International PhD Thesis

PHYSICAL ACTIVITY, PHYSICAL FITNESS, BODY COMPOSITION AND ACADEMIC PERFORMANCE IN CHILDREN AND ADOLESCENTS

Departamento de Educación Física, Deporte y Motricidad Humana

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IRENE ESTEBAN CORNEJO

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Tesis Doctoral Internacional

ACTIVIDAD FÍSICA, CONDICIÓN FÍSICA, COMPOSICIÓN CORPORAL Y RENDIMIENTO ACADÉMICO EN NIÑOS Y ADOLESCENTES

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2014

To those who have always believed in me
A quienes siempre han creído en mí.

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IRENE ESTEBAN CORNEJO

THESIS SUPERVISORS

CARLOS Mª TEJERO GONZÁLEZ, PhD
Facultad de Formación de Profesorado y Educación
Universidad Autónoma de Madrid

ÓSCAR L. VEIGA NÚÑEZ , PhD
Facultad de Formación de Profesorado y Educación
Universidad Autónoma de Madrid

JAMES F. SALLIS, PhD
School of Medicine
University of California San Diego

IN SIVANA....

You are sitting in the middle of a magnificent, lush, green garden. This garden is filled with the most spectacular flowers you have ever seen. The environment is supremely tranquil and silent. Savor the sensual delights of this garden and feel as if you have all the time in the world to enjoy this natural oasis. As you look around you see that in the center of this magical garden stands a towering, red lighthouse, six stories high. Suddenly, the silence of the garden is disturbed by a loud creaking as the door at the base of the lighthouse opens. Out stumbles a nine-foot-tall, nine-hundred-pound Japanese sumo wrestler who casually wanders into the center of the garden.

As this sumo wrestler starts to move around the garden, he finds a shiny gold stopwatch which someone had left behind many years earlier. He slips it on, and falls to the ground with an enormous thud. The sumo wrestler is rendered unconscious and lies there, silent and still. Just when you think he has taken his last breath, the wrestler awakens, perhaps stirred by the fragrance of some fresh yellow roses blooming nearby.

Energized, the wrestler jumpsswiftly to his feet and intuitively looks to his left. He is startled at what he sees. Through the bushes at the very edge of the garden he observes a long winding path covered by millions of sparkling diamonds. Something seems to instruct the wrestler to take the path, and to his credit, he does. This path leads him down the road of everlasting joy and eternal bliss

ROBIN SHAR

EN SIVANA....

Estás sentado en mitad de un espléndido y exuberante jardín. Este jardín está lleno de las flores más espectaculares que has visto nunca. El entorno es extraordinariamente tranquilo y callado. Saborea los sensuales placeres de este jardín y piensa que tienes todo el tiempo del mundo para disfrutar de este oasis. Al mirar alrededor ves que en mitad del jardín mágico hay un imponente faro rojo de seis pisos de alto. De repente, el silencio del jardín se ve interrumpido por un chirrido fuerte cuando la puerta del faro se abre. Aparece entonces un luchador de sumo japonés- mide casi tres metros y pesa cuatrocientos kilos-, que avanza indiferente hacia el centro del jardín.

Cuando el luchador de sumo empieza a moverse por el jardín, encuentra un reluciente cronógrafo de oro que alguien olvidó muchos años atrás. Resbala y al momento cae con un golpe sordo. El luchador de sumo queda inconsciente en el suelo, inmóvil. Cuando ya parece que ha exhalado su último aliento el luchador despierta, quién sabe si movido por la fragancia de unas rosas amarillas que florecen cerca de allí.

Con nuevas energías, el luchador se pone rápidamente en pie y mira intuitivamente hacia su izquierda. Lo que ve le sorprende mucho. A través de las matas que hay al borde mismo del jardín observa un largo y serpenteante camino cubierto por millones de hermosos diamantes. Algo parece impulsar al luchador a tomar esa senda y, dicho sea en su honor, así lo hace. Ese camino le lleva por la senda de la alegría perdurable y la felicidad eterna.

ROBIN SHAR

CONTENTS

I. LIST OF PUBLICATIONS

The present PhD Thesis is based on the following scientific manuscripts:

I. **Esteban-Cornejo I,** Tejero-González CM, Sallis JF, Veiga OL. Physical activity and cognition in adolescents. A systematic review. *Proposed to be accepted* **J Sci Med Sport**

II. **Esteban-Cornejo I**, Tejero-González CM, Martínez-Gómez D, Cabanas-Sánchez V, Fernández-Santos J, Conde-Caveda J, Sallis JF, Veiga OL. Objectively measured physical activity and academic performance in youth. The UP & DOWN Study. *Accepted to* **Acta paediatr.**

III. **Esteban-Cornejo I**, Martínez-Gómez D, Tejero-González CM, Izquierdo-Gómez R, Carbonell-Baeza A, Castro-Piñero, Sallis JF, Veiga OL. Maternal physical activity before and during the prenatal period and the offspring's academic performance in youth. The UP&DOWN Study. *Proposed to be accepted to* **Am J Hum Biol.**

IV. **Esteban-Cornejo I,** Tejero-González CM, Martínez-Gómez D, Del-Campo J, González-Galo A, Padilla-Moledo C, Sallis JF, Veiga OL. Independent and combined influence of the components of physical fitness on academic performance in youth. The UP & DOWN Study. **J Pediatr** (in press).

V. **Esteban-Cornejo I,** Tejero-González CM, Castro-Piñero J, Conde-Caveda J, Cabanas-Sánchez V, Sallis JF, Veiga OL. Independent and combined influence of neonatal and current body composition on academic performance in youth. The UP & DOWN Study. **Pediatric Obesity** (in press).

II. ABSTRACT

Academic performance in youth is an important indicator of adult physical and mental health. An active lifestyle, being physically fit and a healthy body composition during childhood and adolescence may have an influence on academic performance. The overall aim of this PhD Thesis was to analyze the associations of physical activity, physical fitness and body composition with academic performance in children and adolescents.

The current PhD Thesis is based on data from the UP&DOWN Study. A total of 2,225 youth (aged 6-18 years) participated in the study. Physical activity was objectively measured by accelerometry. Maternal physical activity was self-reported. Cardiorespiratory fitness was measured using the 20-m shuttle run test. Motor fitness was assessed with the 4×10-m shuttle-run test. A muscular fitness score was computed using handgrip strength and standing long jump. Neonatal body composition was parent-reported. Current body composition was assessed by body mass index, waist circumference and percentage of body fat. Academic performance was assessed through grades reported by schools.

The main findings found in the current dissertation suggest that (i) physical activity is associated with cognition, and specifically, objectively measured physical activity is related to academic performance in youth, but the magnitude of this association, albeit negatively significant, was very weak; (ii) maternal physical activity before and during pregnancy is positively associated with youth's academic performance. Continuing maternal physical activity practice during pregnancy is associated with greater benefits for youth's academic performance; (iii) cardiorespiratory and motor fitness, as well as neonatal and current body composition, both independently and combined, are associated with academic performance in youth.

III. RESUMEN

El rendimiento académico de los jóvenes es un importante indicador de salud física y mental durante la edad adulta. Un estilo de vida activo, estar físicamente en forma y una composición corporal saludable durante la niñez y adolescencia pueden influir en el rendimiento académico. El objetivo general de esta tesis doctoral fue analizar las asociaciones entre la actividad física, la condición física y la composición corporal, con el rendimiento académico en niños y adolescentes.

La presente tesis doctoral se basa en datos del estudio UP&DOWN. Un total de 2.225 niños y adolescentes (de 6 a 18 años) participaron en el estudio. Los niveles de actividad física se midieron por acelerometría. La actividad física de la madre fue auto-reportada. La capacidad cardiorespiratoria se evalúo mediante el course navette. La habilidad motora se evaluó con el test 4 × 10 m. La fuerza muscular se calculó mediante la prueba de fuerza de presión manual y el salto de longitud. La composición corporal neonatal fue reportada por los padres. La composición corporal actual se evaluó mediante el índice de masa corporal, el perímetro de la cintura y el porcentaje de grasa corporal. El rendimiento académico se evaluó a través de las califiaciones académicas registrasdas oficialmente en los centros educativos.

Los principales hallazgos de la presente tesis sugieren que (i) la actividad física se asocia con la cognición y concretamente, la actividad física medida por acelerometría se asocia con el rendimiento académico de los jóvenes, pero la magnitud de esta asociación, aunque negativa, es muy débil; (ii) la actividad física de la madre antes y durante el embarazo está asociada positivamente en rendimiento académico posterior de los jóvenes; (iii) La capacidad cardiorespiratoria y la habilidad motora, así como la composición corporal neonatal y actual, tanto independientemente como en combinación, se asocian con el rendimiento académico en niños y adolescentes.

IV. ABBREVIATIONS

ALPHA, assessing levels of physical activity

BDNF, brain-derived neurotrophic factor

BMI, body mass index

METs, metabolic equivalents

mRNA, messenger ribonucleic acid

GPA, grade point average

HDL-C, High density lipoprotein cholesterol

IGFBP-1, Insulinlike growth factor-binding protein 1

SRT, shuttle run test

V. INTRODUCTION

Childhood and adolescence are critical stages for cognition (Romeo and McEwen, 2006). Cognition may be an important predictor of physical and mental adult health (Gale et al., 2012). For example, poor cognitive and academic performance during youth have been associated with higher morbidity and mortality, anxiety disorders, depression, psychological distress, coronary heart disease and some cancers later in life (Bhasin et al., 2010; Gale et al., 2009; Jaycox et al., 2009; Lager et al., 2009, Lawlor et al., 2008; Hart et al., 2003). In contrast, a high academic performance is linked to positive psychological-related variables such as self-esteem and self-concept (Fati-Ashtiani et al. 2007).

An active lifestyle during childhood and adolescence may influence levels of physical fitness and body composition. As such, engaging in physical activity, being physically fit and maintaining a healthy body composition may be crucial for a better health later in life (Ruiz et al., 2010). Although their physical health benefits are well-known (Luppino et al., 2010; Ortega et al., 2008; Strong et al., 2005), there is an emerging body of evidence of the potential effects of these health-related factors on academic performance in children and adolescents. Based on the aforementioned evidence, the present PhD Thesis provides new insights on the associations of physical activity (including maternal physical activity before and during pregnancy), physical fitness and body composition with academic performance among children and adolescents within the context of The UP&DOWN Study.

The UP&DOWN Study is a 3-yr longitudinal study to carry out in healthy schoolchildren and in adolescents with Down syndrome to assess the impact over time of physical activity and sedentary behaviors on health indicators such as physical fitness, metabolic and cardiovascular disease risk factors, novel inflammation-immunity biomarkers, mental health as well as to identify the psycho-environmental and genetic determinants of an active lifestyle in these populations.

Initiatives as the UP&DOWN Study contribute to the development of International and European strategies (e.g. the Global Strategy on Diet, Physical Activity and Health and the European Strategy for Child and Adolescent Health and Development). Also, contributing to several National strategies such as the NAOS strategy for obesity prevention and the Integral Plan on Physical Activity and Sport (A+D Plan 2010-2020, Spanish National Sport Council)]. For example, the present PhD contributes to the ongoing Plan on Physical Activity and Sport in one of its main principles: "Physical activity practice and their association with education within the school context". Therefore, the results obtained from the present PhD dissertation will be valuables not only to produce relevant scientific information, but also for future development of the Spanish A+D Plan.

This PhD Thesis is divided into five sections. The first section addresses the framework of the PhD, including five main sub-sections: academic performance, physical activity, physical fitness, body composition. and the associations of physical activity, physical fitness and body composition with academic performance. Each of the four first sub-sections deals with concepts, health-related associations and assessment. The second section explains the main aims and the third section details the methodology of the present PhD Thesis. The forth section addresses results and discussion, including the five scientific papers enclosed in the form they have been published or submitted.

The last section includes the main conclusions of the present PhD Thesis.

VI. INTRODUCCIÓN

La niñez y la adolescencia son etapas críticas para la cognición (Romeo y McEwen, 2006). La cognición puede ser un importante indicador de salud física y mental durante la edad adulta (Gale et al., 2012). Por ejemplo, niveles bajos de rendimiento académico y cognitivo durante la juventud se han asociado con una mayor morbilidad y mortalidad, trastornos de ansiedad, depresión, trastornos psicológicos, enfermedades coronarias y algunos tipos de cáncer más tarde en la vida (Bhasin et al., 2010 ; Gale et al., 2009 ; Jaycox et al., 2009; Lager et al, 2009, Lawlor et al., 2008 ; Hart et al., 2003). En cambio, niveles altos de rendimiento académico se asocian positivamente con variables psicológicas tales como la autoestima y el auto-concepto (Fati - Ashtiani et al., 2007).

Un estilo de vida activo durante la infancia y la adolescencia, puede influir en los niveles de condición física y composición corporal. Como tal, practicar actividad física regularmente, estar físicamente en forma y mantener una composición corporal saludable puede ser crucial para una mejor salud en el futuro (Ruiz et al., 2010). Aunque sus beneficios para la salud física son bien conocidos (Lupino et al., 2010; Ortega et al., 2008 ; Strong et al., 2005), existe un cuerpo emergente de evidencia sobre los efectos potenciales de estos factores relacionados con la salud y el rendimiento académico en niños y adolescentes. Basándose en la evidencia antes mencionada, la presente tesis doctoral proporciona nuevos conocimientos sobre la asociación de la actividad física (incluyendo la actividad física de la madre antes y durante el embarazo), la condición física y la composición corporal con el rendimiento académico de niños y adolescentes en el contexto del Estudio UP & DOWN.

UP & DOWN es un estudio longitudinal de 3 años que se lleva a cabo en escolares sanos y en adolescentes con síndrome de Down con el objetivo de evaluar el impacto en el tiempo de la actividad física y el sedentarismo sobre indicadores de salud, como la condición física, factores de riesgo de enfermedades cardiovasculares y metabólicas, nuevos biomarcadores de inmuno-inflamación y salud mental, así como identificar los determinantes psico-ambientales y genéticos de un estilo de vida activo.

Iniciativas como el Estudio UP & DOWN contribuyen a la elaboración de estrategias internacionales y europeas (por ejemplo, la Estrategia Mundial sobre Régimen Alimentario, Actividad Física y Salud y de la Estrategia Europea para la Salud Infantil y Adolescente y el Desarrollo). Al igual que a estrategias nacionales como la estrategia NAOS para la prevención de la obesidad, y el Plan Integral para la Actividad Física y el Deporte (Plan A + D 2010-2020, Consejo Superior de Deportes). Como tal, la presente Tesis Doctoral contribuyen al Plan Integral para la Actividad Física y el Deporte en uno de sus principios fundamentales: "la práctica de actividad física y su relación con la educación en el contexto escolar". Por lo tanto, los resultados obtenidos en la presente Tesis Doctoral pueden ser relevantes, no sólo para la producción científica, sino también para el desarrollo del Plan A + D 2010-2020.

La Tesis Doctoral se divide en cinco secciones. La primera sección aborda el marco teórico de la Tesis Doctoral, que incluye cinco bloques principales: rendimiento académico, actividad física, condición física, composición corporal y las asociaciones de la actividad física, la condición física y la composición corporal con el rendimiento académico. En cada uno de los cuatro primeros bloques se definen los conceptos, relaciones con la salud y métodos de evaluación. En la segunda sección se explican los objetivos principales, y en la tercera se detalla la metodología de la presente Tesis Doctoral. En la cuarta sección se contemplan los resultados y la discusión, incluyendo los cinco artículos científicos en el modo en que han sido publicados o sometidos. La última sección recoge las principales conclusiones de la presente Tesis Doctoral

VII. FRAMEWORK

Academic performance

Concepts

Academic performance is also known as academic achievement or school performance. The word *academic* is related to what is valued in learning (i.e. academics); there are two main areas: (i) academic content that refers to specific knowledge in different subjects (e.g. Mathematics, Science, Language, Literature) and (ii) academic skills refers to the learned ability to carry out a task (e.g. reading, writing, problems solving) (Amstrong, 2006). *Achievement* refers to the act of achieving or attaining a goal by doing efforts. It indicates the way in which teachers and educators want students to engage in academic content and skills (Simpson and Weiner, 1991). Collectively, academic performance is understood as an educational-related term associated with the extent to which students achieve their educational goals.

The complex debate regarding academic performance is determined by a threefold convergence of school dimensions that generates difficult aims: (i) social dimension, (ii) institutional-educational dimension and (iii) economic dimension (Alvaro-Page et al., 1990):

(i) Social dimension. Schools should help to eliminate social discrepancies between students. In this sense, academic performance is proposed in relation to the equality access to society productive functions in order to achieve the potential benefits of such production later in life.

(ii) Institutional-educational dimension. This dimension is focused on whether the different educational requirements (e.g. curriculum, teachers, organization, teaching methods) are appropriated to achieve the proposed aims.

(iii) Economic dimension. This dimension refers to whether educational investment (i.e. contents and organization) generates the appropriated satisfaction that society demands as well as the expected resources.

From this perspective, defining and delimiting the academic performance term is not a simple task, despite of academic performance is a key aspect of socio-educational research (Adell, 2006; Martínez-Otero, 1997; Álvaro-Page et al., 1990). Several definitions regarding to academic performance have been compiled by Álvaro-Page et al. (1990) and are shown in table 1.

Table 1. Academic performance definitions

Author (year)	Definition
Kaczynska (1965)	Academic performance is defined from a perspective based on willpower. Students' performance depends on their good will or their ill will. It does not consider individual and social factors.
Marcos (1966)	Academic performance as a means through which all educational and formative activities are used
Just (1971)	Academic performance is described from an operational perspective. It is the result of a continued behavior that occurs under control over time.
Bloom (1972)	Academic performance is understood as a result of school work. It is necessary that students are able to put into practice knowledge that they have learn
González Fernández (1975)	Academic performance is seen as a product of several factors derived from: educational system, family and student.
Forteza Méndez (1975)	Academic performance is defined as the productivity carried out by students. This productivity depends on their efforts, attitudes, characteristics and perceptions.
Gimeno Sacristan (1976)	Academic performance is described as grades that students achieve at the end of a school year and depend on student's personality.
Muñoz Arroyo (1977)	Academic performance is defined from a perspective based on capacities. Students' performance depends on their capacities. A high academic performance is expected from a student with high capacities.
Touron (1985)	Academic performance is seen as a result of learning. The most of this learning is caused by teachers and embraced by students.
Gómez Castro (1986)	Academic performance refers to the level of knowledge and abilities that students demonstrate by any assessment method.

Thus, academic performance is a multidimensional concept related to human growth and cognitive, emotional, social, and physical development (Steinberger, 1993). Because of its multidimensional characteristic is not possible to attribute the whole responsibility to schools and it is necessary to take into account familiar, social, cultural, and economic environment in which academic performance is carried out (Álvaro-Page et al., 1990).

On one hand, in an attempt to explain academic performance, Vernon (1950) was one of the first experts that included a broad spectrum of factors, mainly: family environment, school environment, teacher's methodology, student's interest and student's personality. Svensson (1971), in a study focused on academic performance in 10,000 participants, summarized the factors related to academic performance that are included in his approach as follows: aptitude factors, sociological factors and attitudes (personal and familiar). Rodríguez-Espinar (1982) argued that approaches focused on academic performance should produce a circular effect in which there are continued interactions between variables. His approach is shown in figure 1.

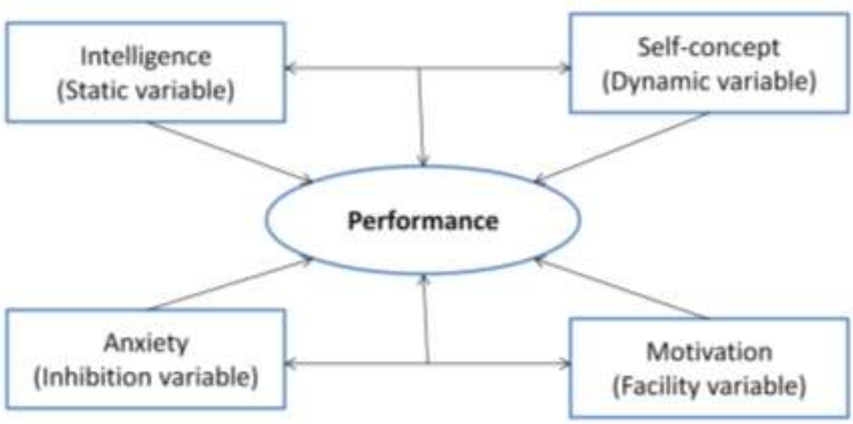


Figure 1. Academic performance variables proposed by Rodríguez-Espinar (1982).

Kirby (1984) has distinguished two main approaches to study the determinants of academic performance. The first approach is focused on personological factors, in which some students achieves better results than others do because they have the appropriate ability in greater measure and possess more relevant or more extensive background knowledge. It is the approach of psychologist interested in individual differences and of the teacher or educator who believe that schools perform a selective than a formative function. The second one empathizes situational factors such as more efficient teaching or greater time spent in tasks; the experimental psychologist relies in this approach in which teachers believe that schools mainly have compensatory and formative functions (Kirby, 1984). Cronbach (1975) asserted that each approach has different limitations and suggested the importance of the mediating and interactive relationship between personological and situational factors in determining academic performance. Figure 2 shows a general model of academic performance with both approaches, in which there are many interrelationships among variables (Kirby, 1984).

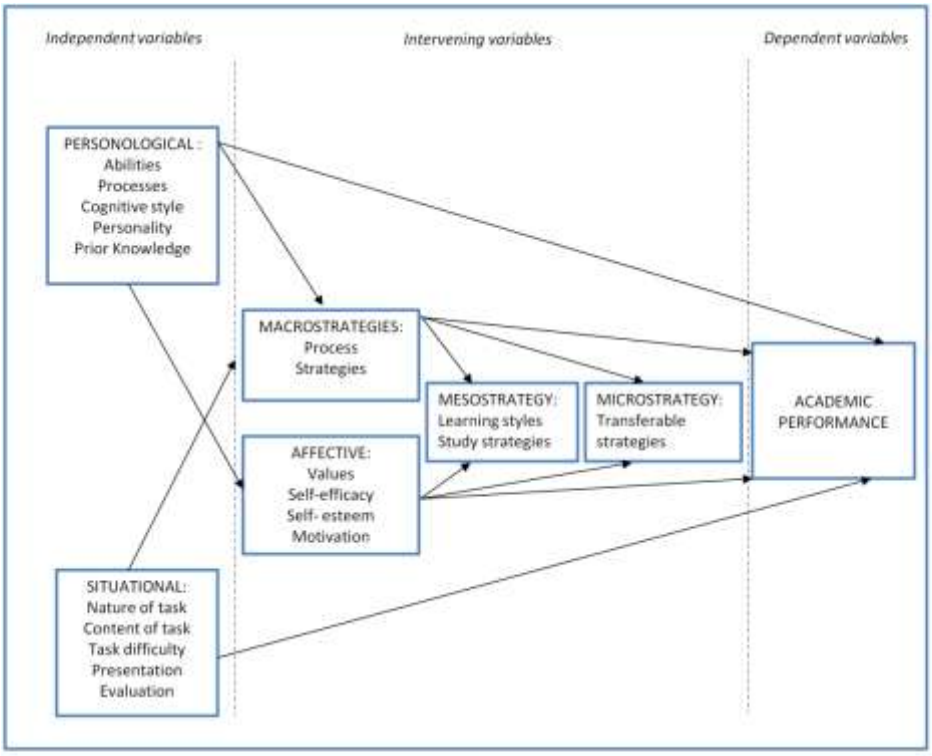


Figure 2. General model of academic performance modified from Kirby (1984).

Another approach proposed by Osca et al. (1990) is focused on the student' transition to professional future (figure 3):

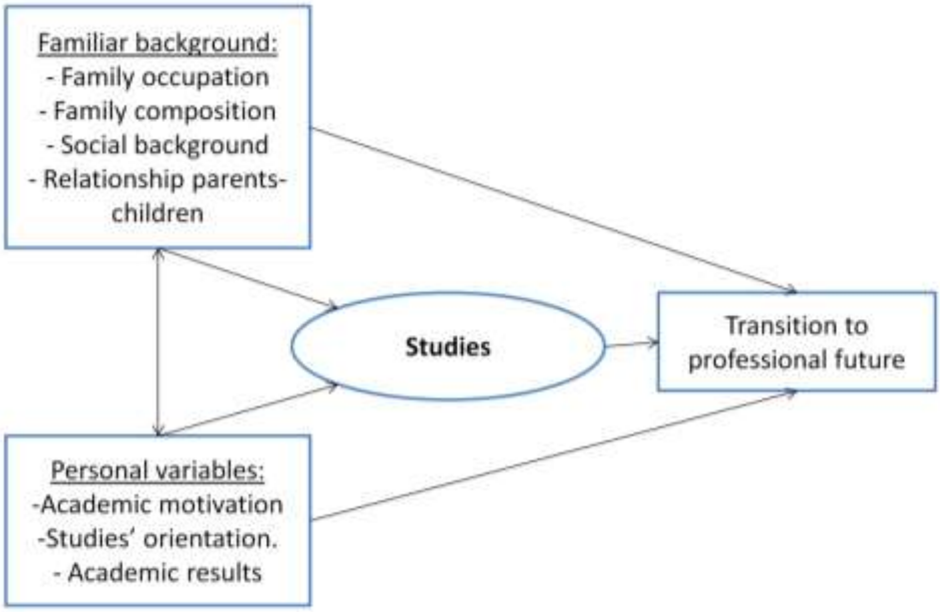


Figure 3. Transition to proffesional future factors proposed by Osca et al. (1990).

Lastly, one of the most recent approach is proposed by Adell (2006) (figure 4). This model defined to study academic performance classified its variables in four main categories: personal factors, familiar factors, school factors and behavioral factors. The performance in this model is defined in terms of grades and academic well-being. The variables that have the highest potential preditor are: academic aspirations, teacher-student relationship, cultural activities and dedication to studies. All variables are directly related to academic performance, except dedication to studies that is inversely related to academic performance. The inverse relationship is due to the fact that studying more hours does not imply better performance and does not generate academic well-being. For this reason it is important to balanace the number of hours dedicated to study as well as to use effective strategies to avoid academic unrest, which in turn, may negatively affect to grades.

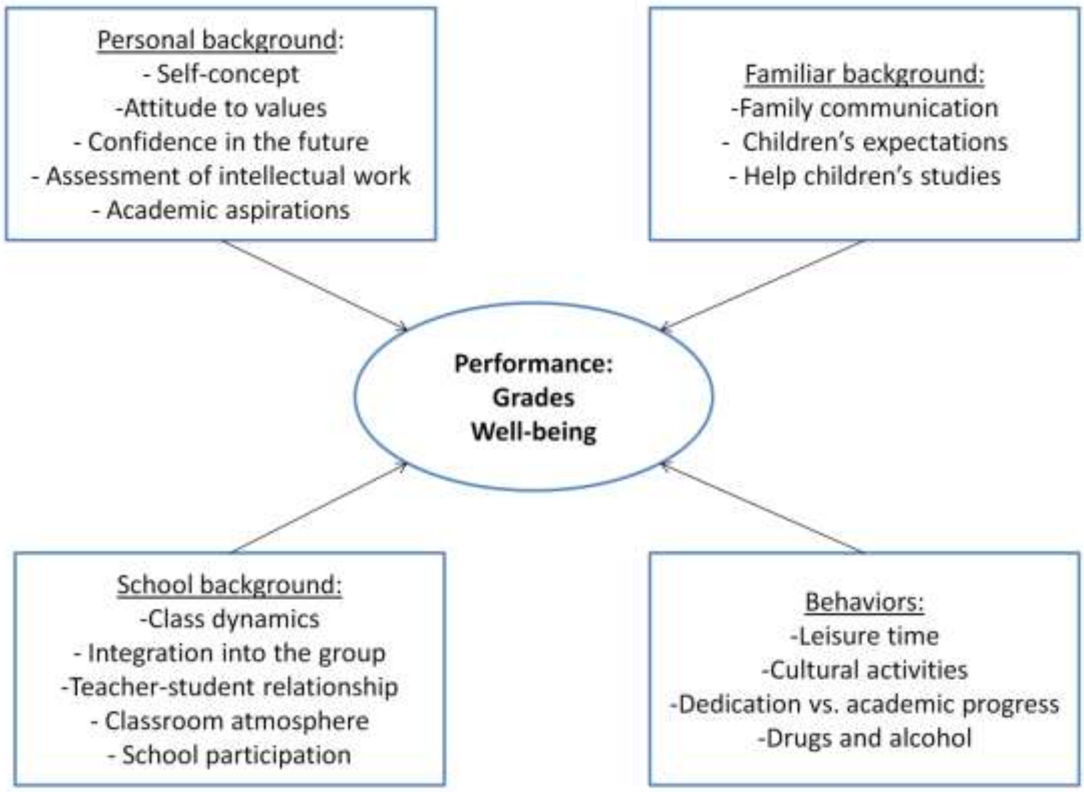


Figure 4. Academic approach proposed by Adell (2006)

As such, there are a huge number of developed aproaches to explain academic perfomance. These approaches have been changed over time, but each of them is based on various factors and these factors are interrelated. In this sense, it is important to take into account the multidimensional characteristic of academic performance when studying this issue.

On the other hand, an emerging body of evidence focused on the underlying cognitive processes that comprise academic performance (Bull et al., 2008; Diamond et al., 2007). In this sense, several cognitive processes have been widely related to academic performance (i.e. general cognitive ability, intelligence, and processing speed, and executive control function) (Hillman et al., 2012). Specifically, executive control function (also known as cognitive control) is one of the most important processes for academic performance, which involves inhibition, working memory and cognitive flexibility (Hillman et al., 2012; Diamond, 2006). Inhibition refers to the ability to filter irrelevant environmental information, override a prepotent response, and stop an ongoing response, abilities that are central to attention and action control. Working memory is defined as an ability to temporarily store and manage information while learning and responding to cognitive challenges. Cognitive flexibility includes the ability to restructure knowledge and information based on changing situational demands (Chaddock et al., 2012; Diamond, 2006; Baddeley, 1992).

Among the cognitive control factors, both inhibition and working memory have been implicated in mathematical and reading ability, however the role of cognitive flexibility on academic performance has not been identified (Bull and Scerif, 2001). For example, a study in students aged 11–12 year identified two separate cognitive control factors, one related to the updating of the contents of working memory and the other associated with the inhibition of irrelevant information. The third cognitive control factor (i.e., cognitive flexibility) was not identified as having a distinct relationship with academic achievement (St. Clair-Thompson and Gathercole, 2006). As such, inhibition and working memory are the factors that play a key role academic performance.

Academic performance and health

Cognition, understood as a broadly term to refer to cognitive and academic performance, has been identified as a powerful marker of health (Gottfredson and Deary, 2004) Variables associated to cognition have been used to assess psychological health in school ages (Strong et al., 2005). Childhood and adolescence are critical stages for cognition (Romeo and McEwen, 2006). Cognition may be an important predictor of adult health. For example, poor cognitive and academic performance during youth have been associated with higher morbidity and mortality, anxiety disorders, depression, psychological distress, coronary heart disease and some cancers later in life. Whereas a high academic performance is linked to positive psychological-related variables such as self-esteem and self-concept (Table 2).

Table 2. Evidence on academic performance and health.

Indicators	***Articles***
Adult health predictor	Martin LT, et al. Cognitive performance in childhood and early adult illness: a prospective cohort study. *J Epidemiol Community Health* 2004; 58(8):674-679.
	Batty GD, Deary IJ. Health communication, intelligence, and health differentials. *Am J Public Health* 2005; 95(7):1088; author reply 1089-1088.
	Gale CR, et al. Intelligence in early adulthood and subsequent hospitalization for mental disorders. *Epidemiology* 2010; 21(1):70-77.
	Gale CR, et al. Cognitive function in childhood and lifetime cognitive change in relation to mental wellbeing in four cohorts of older people. *PloS one* 2012; 7(9):e44860.
	Whalley LJ, Deary IJ. Longitudinal cohort study of childhood IQ and survival up to age 76. *Br Med J* 2001; 322(7290):819-819.
Morbitdity and mortality	Martin LT, Kubzansky LD. Childhood cognitive performance and risk of mortality: a prospective cohort study of gifted individuals. *Am J Epidemiol* 2005; 162(9):887-890.
	Pearce MS, et al. Childhood IQ and deaths up to middle age: The Newcastle Thousand Families Study. *Public Health* 2006; 120(11):1020-1026.
	Lager A, et al. The association of early IQ and education with mortality: 65 year longitudinal study in Malmö, Sweden. *Brit Med J* 2009; 339(7735):1432-1432.
Anxiety disorders	Martin LT, et al. Childhood cognitive performance and risk of generalized anxiety disorder. *Int J Epidemiol* 2007; 36(4):769-775.
	Bhasin SK, et al. Depression, anxiety and stress among adolescent students belonging to affluent families: A school-based study. *Indian J Pediatr* 2010; 77(2):161-165.
Depression	Batty GD, et al. Childhood IQ in relation to later psychiatric disorder: Evidence from a Danish birth cohort study. *Br J Psychiatry* 2005b; 187(2):180-181.
	Jaycox LH, et al. Impact of Teen Depression on Academic, Social, and Physical Functioning. *Pediatrics* 2009; 124(4):e596-e605.
Psychological distress	Gale CR, et al. Cognitive ability in early adulthood and risk of 5 specific psychiatric disorders in middle age: the Vietnam experience study. *Arch Gen Psychiatry* 2008; 65(12):1410-1418.
	Gale CR, et al. Intelligence in childhood and risk of psychological distress in adulthood: The 1958 National Child Development Survey and the 1970 British Cohort Study. *Intelligence* 2009; 37(6):592-599.
Coronary heart diseases	Batty GD, et al. Childhood intelligence in relation to adult coronary heart disease and stroke risk: evidence from a Danish birth cohort study. *Paediatr Perinat Epidemiol* 2005a; 19(6):452-459.
	Lawlor DA, et al. Association of Childhood Intelligence with Risk of Coronary Heart Disease and Stroke: Findings from the Aberdeen Children of the 1950s Cohort Study. *Eur J Epidemiol* 2008, 23(10):695-706.
Cancers	Hart CL, et al. Childhood IQ, social class, deprivation, and their relationships with mortality and morbidity risk in later life: prospective observational study linking the Scottish Mental Survey 1932 and the Midspan studies. *Psychosom Med* 2003;65(5):877-883.
Self-esteem and self-concept	Fati-Ashtiani, A, et al. Relation between Self-concept, Self-steem, Anxiety, Depression and Acedemic achievement in adolescents. *J Appl Sci* 2007; 7(7):995-1000.

An active lifestyle, being physically fit and maintaining a healthy body composition during childhood and adolescence may be important for a better academic performance (Strong et al., 2005), and thus for potential occupational success. To understand in which way these factors may influence academic performance, several mechanisms have been investigated:

(i) *How physical activity affects the brain?:* The effect of physical activity on the brain could be the results of several factors, including increased flow of blood (Vicente-Campos et al., 2012; Jorgensen et al., 2000), and oxygen to the brain (Vicente-Campos et al., 2012), as well as higher levels of chemicals and increased activity-dependent synaptic plasticity (Vivar et al., 2013). Additionally, a study conducted with young male adults evidenced that vigorous activity can increase brain-derived neurotrophic factor (BDNF) and catecholamines (dopamine and epinephrine) (Winter et al., 2007).

These physiological changes may be associated with (i) improved attention, (ii) improved information processing, storage, and retrieval; (iii) enhanced coping; (iv) enhanced positive affect and (v) reduced sensations of cravings and pain.

(ii) How physical fitness affects the brain?: Physical fitness improves cognitive control that involves inhibition, working memory and cognitive flexibility (Diamond, 2013; Pontifex et al., 2011; Chaddock et al., 2010); three aspects that provide the foundation for academic abilities (Chaddock et al., 2012; Agostino et al., 2010). The components of physical fitness with a documented potential to improve health are cardiorespiratory fitness, muscular fitness and motor fitness (Ruiz et al., 2011; Ruiz et al., 2009), each of which may have different effects on the brain. For example, cardiorespiratory fitness is related to angiogenesis (i.e. increases in capillary density), whereas muscular and motor fitness are associated with synaptogenesis (i.e. increases in number of synapses)

On one hand, several mechanisms have been proposed to explain the association between cardiorespiratory fitness and academic performance. First, cardiorespiratory fitness induces angiogenesis in the motor cortex and increases blood flow, presumably to meet the increased metabolic demands of cortical neurons. This phenomenon of brain vascularization improvement could also affect cognitive performance. Second, aerobic physical activity increases BDNF levels that promote neuronal survival and differentiation (Adkins et al., 2006). Lastly, cardiorespiratory fitness is related to higher P3 (P300 wave) event-related brain potential amplitude and lower P3 latency, which reflects a better ability to modulate neuroelectric indices of cognitive control (Pontifex et al., 2011).

On the other hand, two different neuromechanisms could be underlying the association between motor fitness and academic performance. First, motor skills induce syntaptogenesis, increases in BDNF and tyrosine kinase receptors, and reorganization of movement representations within the motor cortex. Second, the spinal cord has a central role in the final common pathway for motor behavior. Specifically operant conditioning of the spinal reflexes may induce spinal cord plasticity through motor skills. Thus, this set of coordinated neuronal changes related to motor fitness might support improved cognitive development (Adkins et al., 2006).

(iii) How body composition affects the brain?: Experimental evidence in neuroscience supports the association between academic performance and multiple body composition indicators at birth and throughout the whole course of life (Liang et al.,2013; Espy et al., 2009). Brain development is highly susceptible to the consequences of preterm birth (Pitcher et al., 2012; Rees and Inder, 2005). A recent study using magnetic resonance imaging showed that low birth weight was associated with smaller brain volumes. Particularly, reduced volume of mid-brain structures, the

caudate and corpus callosum, which are involved in connectivity, executive attention and motor control. These brain abnormalities, in turn, were related to poor academic performance (Clark et al., 2013). Others neuroimaging studies indicated that obesity was associated with detectable structural differences in the brain in youth as well as in younger adults and cognitively healthy elderly subjects (Reinert et al., 2013; Gazdzinski et al., 2008; Pannacciulli, et al., 2006). Prefrontal cortex is a brain region involved in cognitive control, and thus in subsequent academic performance (Agostino et al., 2010; Bunge et al., 2002). Gray matter reductions in prefrontal cortex appear to occur in a dose-dependent manner with increasing body mass index (Agostino et al., 2010; Raji et al., 2010; Taki et al., 2008; Bunge et al., 200236-39). Therefore, unhealthy body composition from birth through adolescence might be inducing an important impairment that hampers learning and academic performance.

Assessment

Academic performance is assessed through various measures; from a wide point of view, in a review from the Center of Diseases Control (2010), academic performance is used broadly to describe different factors that may influence student success in school. These factors fall into three primary areas:

(i) Cognitive skills and attitudes (e.g., attention/concentration, memory, verbal ability).

(ii) Academic behaviors (e.g., conduct, attendance, time on task, homework completion).

(iii) Academic performance (e.g. grades).

Academic performance as an educational goal within the school setting to achieve the high school diploma, it is commonly assessed using grades (i.e. self-reported grades or grades reported by schools) (Sternberg, 2010). In this sense, academic performance is based on different indicators:

(i) Individual grades of several subjects such as Mathematics, Language, Science, English, History and so on. The most frequently subjects used as individual indicators are Mathematics and Language due to the important role of cognitive control (i.e. inhibition and working memory) plays in these areas (Bull and Scerif, 2001).

(ii) An average of specific subjects (i.e. Mathematics and Language). Passing both subjects is taken to indicate good academic performance due to according to the Spanish Educational System (www.educacion.es), the minimum requirement for passing grade is fail in no more than two subjects, whenever these two subjects are not Mathematics and Language.

(iii) Grade point average (GPA) as an average of all examinable subjects. In those educational systems in which school records are defined as letter grades (A, B, C and so forth), each letter is assigned a number, and the numbers are averaged.

Although grades are socially valid measures of academic performance, but they have potential limitations of bias; several factors can affect the objectivity of grades (Alvaro-Page et al., 1990):

(i) Teacher tiredness, for example, when teachers mark exams.

(ii) Expectatives (i.e. positives or negative attirbutions) that teachers have about students.

(iii) Comparation effect. Teachers usually compare performance between students in order to define each mark.

(iv) Organization that students show in written exams (i.e. good presentation or originallity responses).

(v) Other factors such as type of school, culture or social origin.

Physical activity

Concepts

Physical activity is defined as "any bodily movement produced by skeletal muscles that results in caloric expenditure" (Caspersen et al., 1985, p.126). It includes all types of movements and contributes to the overall energy expenditure. In 2008, the US Department of Health and Human Services (2008b, p.2) defined physical activity as "any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level". The term exercise describes different concepts. Exercise is defined as that physical activity which is planned, structured, repetitive, and maintains or improves physical fitness. In turn, physical fitness is a set of outcomes or traits that relates to the ability to perform physical activity. Hence, physical activity is viewed as a health-related behavior that can influence the development of physical fitness (Welk, 2002; Caspersen et al., 1985).

As a behavior, physical activity can be described in several dimensions. The variables of type, frequency, intensity and duration are commonly used to characterize activity patterns (Corbin et al., 2006; Welk et al., 2000), but the World Health Organization refers to the contexts of physical activity as another dimension in which activities occur:

Context of physical activity refers to the purpose or circumstances under which activities are performed. As such, there are four main physical activity domains: (i) leisure-time/sport and recreation, (ii) occupation, (iii) transportation and (iv) incidental/other (e.g. household or cultural activities)(World Health Organization,2010).

Mode refers to the specific type of activities, which can also be classified into different categories (e.g., aerobic or anaerobic, weight bearing or non-weight bearing, continuous or intermittent) (Corbin et al., 2006; Welk, 2002).

Frequency refers to the number of repetitions within a particular time period. It is usually measured as number of days per week (Corbin et al., 2006; Welk, 2002).

Duration describes the amount of physical activity performed within a set time period (e.g. per day, last 7 days) and is typically expressed in minutes (Corbin et al., 2006; Welk, 2002).

Intensity refers to the physical effort required to perform an activity or the energy expenditure per time period. Physical activity is usually categorized as light physical activity, moderate physical activity or vigorous physical activity. On the other hand, intensity can be expressed in absolute or relative terms (Corbin et al., 2006; Welk, 2002).

(i) Absolute intensity is the rate of energy expenditure during a specific time period. The most common units to express absolute intensity are the rate of oxygen uptake (VO_2;l/min) or oxygen uptake in relation to body weight (ml/kg/min). It can also be expressed as kilocalories or kilojoules, or metabolic equivalents (METs). Cut-points based on accelerometer counts are acceptable for classifying the intensity of activities.

(ii) Relative intensity is influenced by several factors (e.g. age, sex, weight). In this sense, intensity is categorized in relative terms. It is typically expressed as a percentage of an individual's aerobic capacity (%VO_{2max}) or VO2 reserve (%RVO_{2max}), or as a percentage of an individual's measured or estimated maximum heart rate (%HR_{max}).

METs are usually used to equate different types of activity. As such, all activities can be compared on standard scale. One MET is considered to represent resting energy expenditure, or approximately 3.5 ml/kg/min in term of oxygen consumption. Because the more physical activity intensity the more increases in oxygen consumption, activities can be quantified in term of multiples of this resting oxygen consumption. For example, a 3 METs activity requires 3 times the oxygen consumption of rest and a 8 METs activity requires 8 times the resting level (Corbin et al., 2006).

The main limitation of METs as a standard scale is that it does not take into account the adaptability of the body to physical activity. In general, individuals may have a similar response to physical activity, but the response´s magnitude depends on the current level of physical fitness/activity of a person. For example, fit individuals can do more physical activity at the same level of response than unfit individuals. Thus, several important principles of physical activity provide the basis for determining the correct dose of physical activity (Corbin et al., 2006):

The *overload* principle indicates that increasing demands are required to achieve health benefits. For example, the health benefits associated with metabolic fitness may require overload, albeit to less extent, than for health-related fitness improvement but overload is required.

The principle of *progression* emphasizes that overload should increase in a gradual way over a period of time to achieve benefits. A person should start slowly and gradually increase physical activity.

The principle of *specificity* indicates that to benefit from physical activity, it is necessary to overload specifically for such benefit. Each component of fitness required a specific type of activity. For example, strength exercises may contribute little for developing cardiorespiratory fitness, as well as stretching exercise do little for modifying body composition.

The principle of *reversibility* can be defined as the overload principle in reverse. It is necessary to maintain physical activity practice in order to maintain health benefits.

Lastly, the principle of *diminishing returns* indicates that health benefits that a person achieves are reduced when a routine is acquired. So that, as fit individuals do not get the same benefits that unfit individuals, as well as when a person get fitter do not get the same benefit for each additional amount of physical activity.

Physical activity and health

The Surgeon General's Report on Physical Activity and Health was an especially important document that informed of the risks of sedentary behavior and the health benefits of physical activity in adults (U.S. Department of Health and Human Services, 1996). Recent evidence has shown the healthy benefits of regular physical activity in children and adolescents (table 3).

Table 3. Healthy benefits of physical activity in children and adolescents (Strong et al., 2005).

Healthy benefits of physical activity	
Adiposity	Reduce total body in overweight children and adolescents
	Reduce visceral adiposity in overweight children and adolescents
Cardiovascular health	Improve in elements of the metabolic syndrome (e.g. adiposity, glucose) in non-obese youth
	Reduce triglyceride and insulin level in overweight children
	Increase HDL-C (high density lipoprotein cholesterol) and triglyceride in school-children
	Reduce blood pressure in youth with mild essential hypertension
	Benefit cardiovascular autonomic tone
	Improve aerobic fitness
Musculoskeletal health and fitness	Improve muscular strength and endurance
	Improve bone mineral content, bone mineral density and bone mineral apparent density in pre-pubertal age and in the early stages of puberty
Mental health	Reduce anxiety and depression symptoms
	Have a positive effect on global, physical, social and academic self-concept
Academic performance	Increase academic and intellectual performance
	Improve concentration, memory and classroom behavior

Such benefits are often framed in the context of the future health status of the individual. It is also important to take into account physical activity as it relates to the multiple demands of childhood and adolescence associated with physical growth, biological maturation, and behavioral development (Strong et al., 2005). Additionally, the evidence has led to recent reports, such as *the Healthy People 2020* in the United States, that establishes health goals, recognizes the importance of physical activity and includes new specific physical activity goals.

To achieve the aforementioned health benefits, recommendations for appropriate amounts of physical activity for children and adolescents have been developed by several organizations and agencies (Strong et al., 2005). The International Consensus Conference on Physical Activity Guidelines for Adolescents established the first age-appropriate physical activity guidelines. First, all adolescents should participate in physical activity every day as part of their lifestyles. Second, adolescents should engage at least in 20 minutes of moderate to vigorous physical activity three sessions per week (Sallis & Patrick, 1994). Subsequently, strong evidence based-data from Strong et al. (2005) showed that children and adolescents should participate every day in at least 60 minutes of enjoyable physical activity that requires moderate to vigorous levels of exertion (Strong et al., 2005). In 2008, the US Department of Health and Human Services (2008b) developed Physical Activity Guidelines for children and adolescents aged 6 to 17 years. Youth should do 60 minutes or more of physical activity each day. Most of the 60 minutes should be either moderate-or vigorous- intensity aerobic physical activity, and should include at least 3 days of vigorous-intensity physical activity. As part of their 60 minutes or more of daily physical activity youth should include as age-appropriate muscle- and bone–strengthening activities on at least 3 days a week. In 2010, the World Health Organization developed similar Physical Activity

Recommendations for children and adolescents aged 5-17 years: youth should accumulate at least 60 minutes of moderate- to vigorous-intensity physical activity daily and the majority of this physical activity should be aerobic. Physical activity at vigorous intensity should be included, as well as those exercises that strengthen muscle and bone, at least 3 times per week.

Assessment

Physical activity is multidimensional, and a complex behavior to measure; no single method can capture all domains. Several measures have been used to assess physical activity in children and adolescents. Such physical activity measures can be classified into three categories: (i) primary measures or gold standards, (ii) secondary or objective measures and (iii) subjective or self-reported measures (figure 5). Gold standards measures, such as direct observation, doubly labeled water and indirect calorimetry, are considered the primary standards for assessment of physical activity. However, we only describe the objective and subjective physical activity measures since the present PhD Thesis is focused on a population based-study, in which it is common to assess physical activity in free-living conditions for a full day during a typical week (Warren et al., 2010; Welk, 2002; Sirard and Pate, 2001).

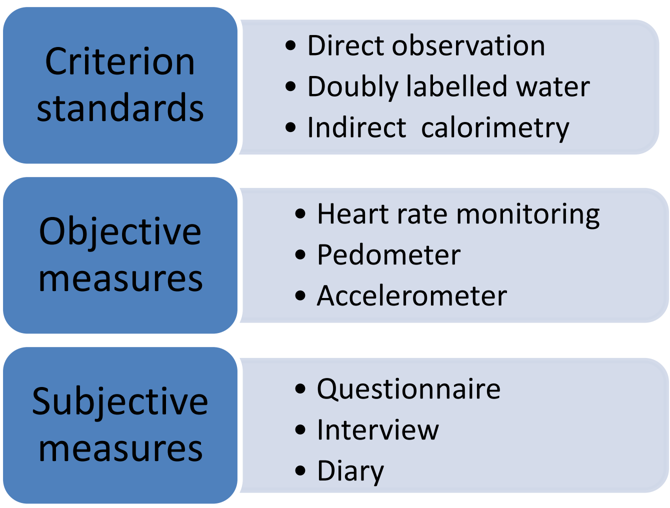


Figure 5. Measures of physical activity.

Several *objective* measures, such as heart rate monitors, pedometers and accelerometers are widely available for measurement of physical activity (Welk, 2002; Sirard and Pate, 2001):

(i) Heart rate monitoring as a means of estimating energy expenditure provides an objective indicator of the physiological effect of physical activity. They have been found to provide a valid measure of heart rate in children and adolescents and rely in the linear relationship between heart rate and oxygen consumption (VO_2). However, this linear relationship is slight at the end of the physical activity spectrum. When individuals perform activities at sedentary or light intensities, their heart rate can be affected by numerous other factors (e.g. medications, caffeine, psychological stress) which contribute to a considerable measurement error. In this sense, the FLEX heart rate method has been used to limit this error. The FLEX heart rate determines an individually heart rate, measured in conjunction with $VO_{2,}$ and differentiates between resting and activity energy expenditure. Resting metabolic rate is substituted for periods when the heart rate falls below the FLEX heart rate (Warren et al., 2010; Sirard & Pate, 2001).

Most heart rate monitors (figure 6) can be programmed to record data at specified intervals (e.g. 60 seconds, 10 seconds). These monitors use the electrocardiogram signal to detect each beat via an electrocardiogram transmitter which is wore in the chest. When the signals are transmitted to the device, a timing circuit measures the interval between heartbeats and it is calculated a moving heart rate average for each defined time period (Welk, 2002)

Figure 6. Heart rate monitor (www.polar.com).

(ii) Pedometers are relatively simple electronic devices used to estimate the number of steps taken (figure 7). They can be used to estimate the energy expenditure associated with walking (Warren et al., 2010; Sirard and Pate, 2001). Studies in children and adolescents have shown favorable validity and reliability (Jago et al., 2006; Tudor-Locke et al. 2002). The main advantages of pedometers are the low cost and ease of use, however they have several disadvantages such as the inability to record non-locomotor movements and the inability to examine the intensity of movements. Although participants could record the number displayed on the pedometer at regular intervals to better capture patterns of activity, this practice would decrease objectivity (Sirard & Pate, 2001; Welk, 2002).

Figure 7. Electronic pedometer (www.yamax.co.uk)

(iii) Accelerometers measure acceleration of the body in a specific dimension (i.e. uniaxial) or in multiple dimensions (e.g. triaxial). The device is usually wore in the hip (or lower back, ankle, wrist or thigh) by a strap; although the wearing position is assumed not to be important at a group level, the most preferable position to wear the accelerometer is hip or lower back. However, there are several types of accelerometers (figure 8) and the wearing position may be different for each type of accelerometer. Accelerometers are the most popular technique for assessing physical activity in free-living conditions. To determinate habitual physical activity it is necessary to measure over multiple days, however there is no consensus about the exactly number of days necessitated to define it. Additionally, there is a range in day-to-day variation regarding physical activity practice in different populations. For example, it may be more variable in children and adolescents requiring a longer wearing time (4–9 days) (Cain et al., 2013; Warren et al. 2010; Welk, 2002).

Data can be collected in a predetermined epoch (i.e. brief time sampling intervals usually between 2 and 60 seconds) or in raw (i.e. counts, the product of the amplitude and frequency of the vertical acceleration). Devices provide information on the intensity of the acceleration or movement at user-specific cut-points (Welk et al., 2000; Sirard & Pate, 2001). The selection of a cut-point may have an important influence on the physical activity intensity levels and depends on the activities performed when calibrating accelerometer output to energy expenditure (Freedson et al., 2005). The cut-point value of <100 count per minutes is used to estimate sedentary time. For moderate to vigorous intensity activities, the range is between 1900 and 8200 counts per minute. This variability means that time spent at different intensity levels may differ substantially in the same dataset dependent on the thresholds chosen (Cain et al., 2013)

Figure 8. Types of accelerometers

The limitations of accelerometers include their inability to capture upper body movement or cycling, because the instrument is mainly wore at the waist. Accelerometers also underestimate the energy expenditure of walking on an incline or carrying heavy loads because the acceleration patterns remain essentially unchanged under these conditions. Additionally, the majority of devices are not waterproof and must be removed before water-based activities such as swimming (Warren et al., 2010; Welk et al., 2000).

Self-report measures are the most widely used instruments to assess physical activity because of low cost and easy way to collect physical activity data from a large number of people in a short time. The term self-report includes a variety of assessment methods: questionnaires, physical activity diaries and interviews. Self-report techniques have several limitations. First, individuals, specifically children and adolescents, may misunderstand the questions. Second, participants may have difficulties in recalling the time or intensity of physical activity. Additionally, the self-report instrument may not detect one or more dimensions of physical activity (frequency, context, type, intensity and duration) (Warren et al., 2010; Welk, 2002). However, the use of structured questionnaires provides information on participation in physical activity by domains (e.g. recreational physical activity, school activities, physical activity for transport) which cannot be obtained with objective measures of physical activity. Besides, questionnaires also may estimate physical activity energy expenditure and time spent at different intensities (Warren et al., 2010).

Physical fitness

Concepts

Physical fitness is considered an integrated measurement of all functions (skeletomuscular, cardiorespiratory, hematocirculatory, psychoneurological, and endocrine-metabolic) and structures involved in the performance of physical activity and /or exercise (Castillo et al. , 2006). "Physical fitness is associated with a person´s ability to work effectively, enjoy leisure time, be healthy, resist hypokinetic diseases or conditions, and meet emergency situations"(Corbin et al., 2006, p.6). There are many factors which help to develop physical fitness, but regular physical activity is the key aspect to achieve optimal physical fitness. It is a multidimensional state of being that usually refers to two aims: performance, which consists of six skill-related fitness components, and health that includes five health-related fitness components, each of which contributes to total quality of life (Corbin et al., 2006; Bouchard and Sheppard, 1994). In addition, there are two components of physical fitness which are not included within these aims; that is, metabolic fitness and bone integrity. These components are considered to be nonperformance measures of fitness and cannot be measured with performance techniques as can most health-related fitness parts. Both, bone integrity and metabolic fitness, are associated with physical activity. Additionally, strong, healthy bones are important to optimal health and good metabolic fitness reduces the risk for many chronic diseases (Corbin et al., 2006).

Skill-related physical fitness is defined as those components of fitness that are necessary for optimal work or sports (Corbin et al., 2006; Bouchard & Sheppard, 1994). The six components of skill-related physical fitness are agility, balance, coordination, power, reaction time and speed (Table 4) and these components are more related to performance than to health (Corbin et al., 2006).

Table 4. Components of skill-related physical fitness (Corbin et al., 2006).

Agility	The ability to rapidly and accurately change the direction of the movement of the entire body in space. Skateboarding is a example of activity that require exceptional agility
Balance	The maintenance of equilibrium while stationary or while moving. Water skiing or rhythmic gymnastics are activities that need good balance.
Coordination	The ability to use the senses with the body parts to perform motor tasks smoothly and accurately. Kicking a ball or hitting a paddle ball are examples of activities that require exceptional coordination
Power	The ability to transfer energy into force at a fast rate. For example, throwing the discus requires considerable power
Reaction time	The time elapsed between stimulation and the beginning of a reaction to that stimulation. Starting a sprint race needs exceptional reaction time.
Speed	The ability to perform a movement in a short period of time. A runner on a track team require good foot and leg speed.

Health-related physical fitness is considered as "the ability to perform daily activities with vigor, alertness and without undue fatigue, as well as traits and capacities that are associated with a low risk of chronic diseases and premature death" (Caspersen et al., 1985, p.128). In 1994, Bouchard and Shepard also defined health-relate physical fitness as having "an ability to perform daily activities with vigor"(p.81). The components of health-related physical fitness are directly associated with good health. These five components are body composition, cardiovascular fitness, flexibility, muscular endurance, and strength (Corbin et al., 2006; Caspersen et al., 1985) (Table 5).

Other experts refer to the health-related physical fitness components as (i) cardiorespiratory fitness, (ii) muscular fitness, (iii) motor fitness and (iv) body composition (Ruiz et al., 2011; Bouchard & Sheppard, 1994).

Table 5. Components of health-related physical fitness (Corbin et al., 2006).

Body composition	The relative percent-age of muscle fat, bone and other tissue that comprise the body. A fit person has relatively low percentage of body fat.
Flexibility	The range of motion available in a join. It is affected by muscle length, joint structure, and other factors. A fit person can move the body joints through a full range of motion (e.g. an oversplit).
Strength	The ability of the muscles to exert an external force or to lift a heavy weight. A fit person can do work that involve exerting force (e.g. weight lifting).
Cardiovascular Fitness	The ability of the heart, blood vessels, blood, and respiratory system to supply fuel and oxygen to the muscles and the ability of the muscles to utilize fuel to allow sustained physical activity. A fit person can do physical activity for long periods without excessive stress
Muscular endurance	The ability of the muscles to exert themselves repeatedly. A fit person can do repeatedly movements for long periods without excessive fatigue.

The components of physical fitness, albeit are specific and different, are also interrelated. Fit individuals have adequate levels of each of components of physical fitness (i.e. the health-related components, skill-related components, metabolic fitness components and bone integrity), but unfit individuals can possess one component of physical fitness and do not possess the other components. For example, individuals who have good cardiovascular fitness do not necessarily have good strength, as well as individuals who possess good balance do not necessarily have good agility (Corbin et al., 2006).

Physical fitness and health

Physical fitness is an important health-related marker during youth and later in adulthood (Ruiz et al., 2009; Ortega et al., 2008b). Higher levels of physical fitness decrease the risk for developing long-term cardiovascular and metabolic diseases, obesity and musculoskeletal problems (Andersen et al., 2008;U.S Department of Health and Human Services, 2008a; Brage et al., 2004). In addition, good fitness contributes to wellness by helping people look better, feel good, and enjoy life. For optimal health and wellness, it is important to have a good physical fitness. It is also important to strive for good emotional-mental, social, spiritual, and intellectual health and wellness (Corbin et al., 2006). Furthermore, mental disorders such as depression and anxiety, neurocognitve diseases (i.e. Parkinson and dementia) and other cognitive impairments seem to benefit from increase in physical fitness (Koivukangas et al., 2010; Stroth et al., 2010). Thereby, being physically fit might improve brain health (Pontifex et al., 2011; Van Dusen et al., 2011; Chaddock et al., 2012).

Assessment

Measurements of physical fitness are provided to understand the nature of total physical fitness and to make decisions about lifetime's physical activity. In the last few years, the relevance of physical fitness assessment in youth and adults has increased. There are specific measurements to assess physical fitness for both youth (e.g. Fitnessgram) and adults (e.g. The Eurofit for adults Test Battery, The ALPHA-FIT Test

Battery for adults, The Senior Fitness Test), but we only describe the measures for youth since the present PhD focuses on children and adolescents. For them, physical fitness can be objectively and accurately measured through different laboratory methods, such as treadmill test (Cureton et al., 1995), isokinetic dynamometry (De Ste Croix et al., 2003), cycle ergometer (Buono et al., 1991), or 1 repetition maximum (Milliken et al., 2008). However, these measures are not feasible for field use due to the necessity of sophisticated instruments, qualified technicians, and time constraints. Field tests are commonly used in population based-studies, especially in the school setting, since they are time efficient, low in cost and equipment requirements, and can be easily administered to a large number of people simultaneously (Ruiz et al., 2011). During the last two decades numerous field-based test batteries have been developed to assess fitness in young population (table 6) (Castro-Piñero et. al, 2010). Two of the most known tests used in children and adolescents are the FitnessGram Test Battery in USA and the ALPHA (Assessing Levels of Physical Activity; www.thealphaproject.eu) Health-related Fitness Test Battery in Europe.

The FitnessGram Test Battery was implemented in phases with the first pilot study conducted in 30 schools in the Tulsa, Oklahoma School District (1982-83) using the American Alliance for Health, Physical Education, and Recreation Youth Fitness Test. Nowadays, is an educational assessment and reporting software system that has been used worldwide to help teachers track health-related fitness information over time and produce personalized reports for children, parents, and school administrators. It represents an important innovation in the field of physical education and youth fitness and has pushed the evolution of physical fitness within four major areas: (i) a commitment to the concept of health-related physical fitness, (ii) a concentration on criterion-referenced evaluation in place of percentile norm-referenced evaluation, (iii) a consistent emphasis on fitness behavior, and (iv) systematic updating and sophistication of the computerized reporting system (Plowman et al., 2013).

Table 6. Field-based fitness test batteries for children and adolescents modified from Castro-Piñero et al. , 2010.

Test	Acronym	Region	Age (yr)
Assessing levels of physical activity	ALPHA	Europe	6-18
Fitnessgram test battery	FITNESSGRAM	USA	5-17
Eurofit Battery	EUROFIT	Europe	6-18
President's Challenge: Health Fitness	PCHHF	USA	6-17
President's Challenge: Physical Fitness	PCPF	USA	6-17
Amateur Athletic Union Test Battery.	AAUTB	USA	6-17
YMCA Youth Fitness Test	YMCAYFT	USA	6-17
National Youth Physical Program.	NYPFP	USA	5-17
Health-Related Fitness Test	HRFT	USA	5-18
Physical Best Test	Physical Best	USA	5-18
International Physical Fitness Test	IPFT	USA	9-19
Canadian Association for Health, Physical Education and Recreation- Fitness Performance Test II	CAHPER-FPT II	Canada	7-69
The Canadian Physical Activity, Fitness & Lifestyle Approach	CPAFLA	Canada	15-69
National Fitness Test Program in the Popular Republic China	NFTP-PRC	China	9-19+
New Zealand Fitness Test	NZFT	New Zealand	6-12
Australian Fitness Education Award	AFEA	Australia	9-19

FitnessGram classifies the dimensions of health-related fitness into three main categories (i) aerobic capacity, (ii) musculoskeletal fitness including muscle strength, muscular endurance, and flexibility, and (iii) body composition. Each category is assessed through a variety of tests. Aerobic capacity is assess using three field tests: the PACER (Progressive Aerobic Cardiovascular Endurance Run), the One-Mile Run, and a walk test (for adolescents 13 years of age or older) (Cureton et al., 2013). The selected musculoskeletal fitness assessments and corresponding muscular functions are shown in table 7 (Plowman, 2013). Body composition is assessed through percent body fat from triceps and calf skindfolds or bioelectric impedance analysis. A second method, based on height and weight, called body mass index (BMI), is also available for being a proxy for body fatness (Going et al., 2013).

Table 7. Musculoskeletal Assessments Used in the Fitnessgram Battery Function.

Function	Recommended Test	Optional Test Items
Abdominal strength and endurance	Curl-up	
Trunk extensor strength and flexibility	Trunk lift	
Upper body strength and endurance	900 Push-up	Modified pull-up Flexed arm hang
Hamstring flexibility	Back-save sit and reach	
Shoulder flexibility	Shoulder stretch	

All tests showed high validity and reliability for the standard and the criterion. The standard represents the level of risk for the health outcomes related to the fitness component being tested. It may be a single score or a range of scores (Morrow et al., 2013). FitnessGram uses a range of scores called the Healthy Fitness Zone for each test item. Performance on musculoskeletal components is classified in two general areas: the “Healthy Fitness Zone” and the “Needs Improvement” Zone (figure 9) .

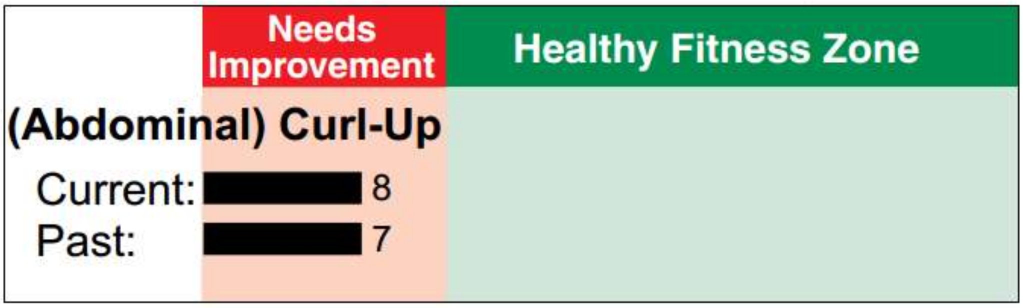


Figure 9. The Healthy fitness zones for curl-up (www.fitnessgram.net).

Performance on the body composition and aerobic capacity components is classified in three general areas: the "Healthy Fitness Zone", the "Needs Improvement Zone", and a "Needs Improvement-Health Risk Zone". A score in the "Healthy Fitness

Zone" represents the level of fitness that provides some protection from the potential health risks. The "Needs Improvement Zone" indicates a level of fitness that is below the minimal health standard. The "Needs Improvement-Health Risk Zone" is used for both aerobic capacity and body composition, and youth in this zone are at greater risk of chronic health conditions such as diabetes and cardiovascular disease in the future (Meredith et al., 2013).

The *ALPHA Health-related Fitness Test Battery* was developed under the framework of the ALPHA study to provide a set of valid, reliable, feasible and safe field-based fitness tests for the assessment of health-related physical fitness in children and adolescents, to be used in the public health monitoring system purposes at population level in a comparable way within the European Union. The process to develop this battery is shown in figure 10 (Ruiz et al., 2011).

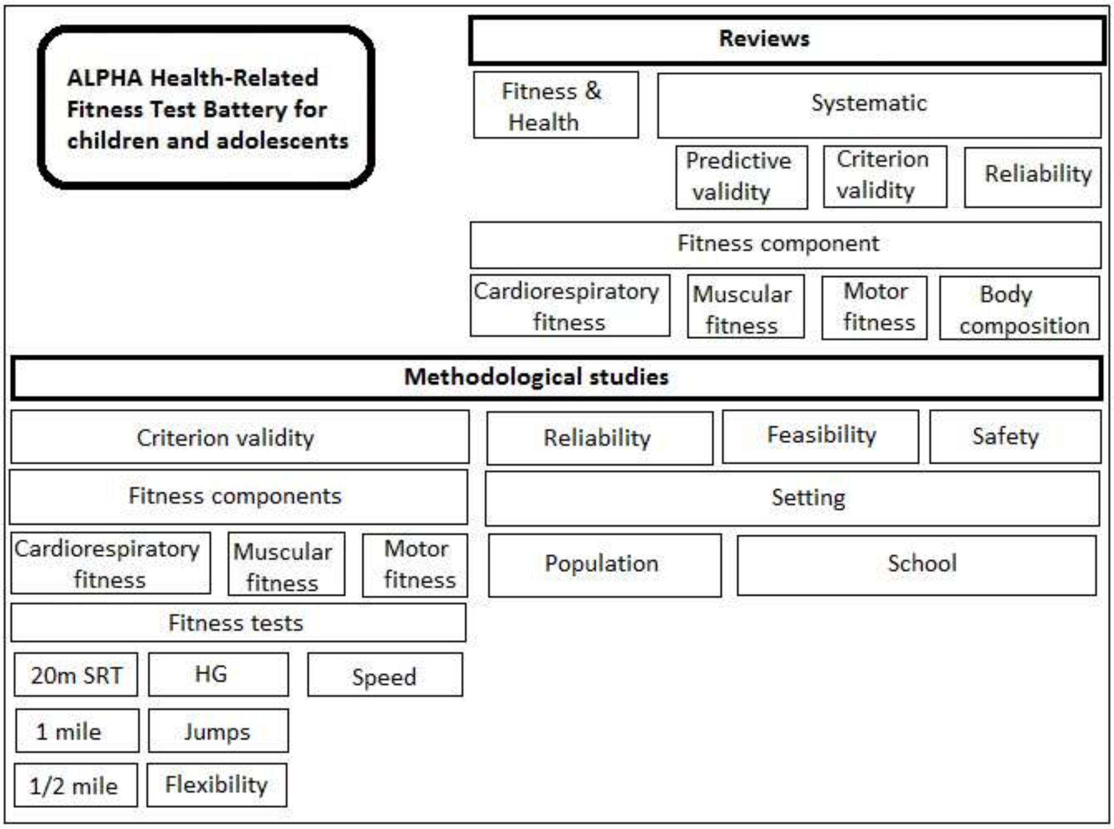


Figure 10. Flow chart of the development of the ALPHA Health-related Fitness Test Battery for children and adolescents modified from Ruiz et al., 2011. SRT, shuttle run test; HG, handgrip.

Firstly, the evidence was reviewed on (i) the association between physical fitness and health in young people mainly focused on finding from cross-sectional studies, (ii) the predictive validity of health-related fitness, (iii) the criterion validity of field-based fitness tests and (iv) the reliability of field-based fitness tests in young people (Artero et al., 2011a; Castro-Piñero et al.,2010; Ruiz et al, 2009; Ortega et al., 2008a). Secondly, eleven methodological studies to determine the criterion validity and the reliability of several field-based fitness tests for young people were carried out. Lastly, it was performed a study in the school setting to examine the reliability, feasibility and safety of the evidence-based selected tests (Ruiz et al., 2011).

The ALPHA fitness test battery includes the following tests: (i) the 20-m SRT (shuttle run test) to assess cardiorespiratory fitness; (ii) the handgrip strength and, (iii) the standing broad jump tests to assess muscular fitness; (iv) BMI, (v) waist circumference, (vi) and skinfold thickness (triceps and subscapular) to assess body composition and (vii) the 4×10-m SRT to assess motor fitness. Although all these measurements have shown to be strongly related with the current and future health status of the children and adolescents, the 4x10-m SRT has shown a poorer health- and criterion-related validity, but only because of a low number of studies (Ruiz et al.,2011).

The ALPHA Fitness Test Battery presents three slightly different versions depending on the available time to administer the tests:

(i) The Extended ALPHA Health-related Fitness Test Battery. In those cases where there are no time limitations, this is the most recommend battery since all the aforementioned tests are included.

(ii) The Evidence-based ALPHA Health-related Fitness Test Battery. This version of the battery includes all the tests with the exception of the 4×10-m SRT. The time needed to administer this battery to a group of 20 individuals by one tester is around 2 hours and 30 minutes.

(iii) High priority ALPHA Health-related Fitness Test Battery, which includes all the tests from the evidence-based ALPHA health-related battery omitting the assessment of the skinfold thickness. The time required to administer this battery to a group of 20 children by one tester is less than 2 hours.

Pubertal development of youth is also assessed due to the fact that several developmental changes are expected to occur during childhood and adolescence. The evaluation of pubertal development should be ideally carried out by a pediatrician or trained physician through direct observation, however this is not feasible in most setting, specifically in school setting. As an alternative, trained researchers can ask youth to categorize themselves in one of the five stages of pubertal maturity defined by Tanner and Whitehouse (Tanner and Whitehouse, 1976).

The recommendation on the most appropriate sequence to administer this battery is shown in figure 11.

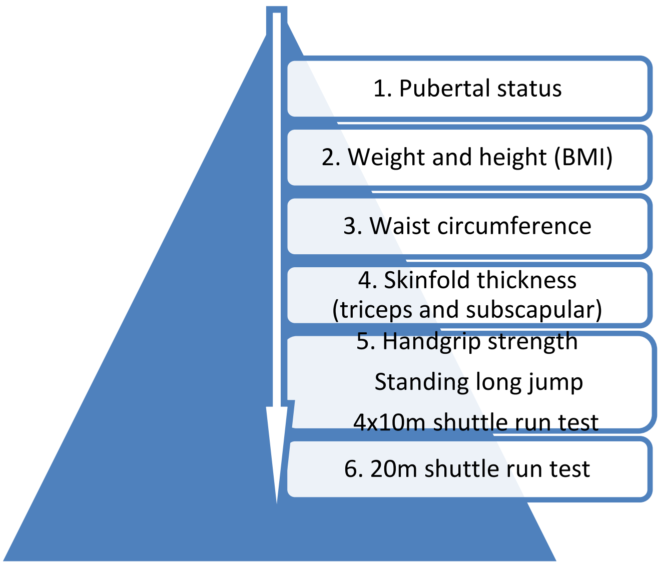


Figure 11. Recommended sequence of the ALPHA fitness test battery.

For each of the tests, there are normative values in order to correctly interpret the fitness status as well as to evaluate effects of potential interventions and to identify youth at risk for the major public health diseases (http://www.thealphaproject.eu/). It is important to monitor health-related fitness in order to avoid disease risk and to enhance physical functional capacity for everyday life.

Body composition

Concepts

Body composition refers to "the relative proportions of body weight in terms of lean body mass and body fat. Lean body mass represents the weight of muscle, bone, internal organs and connective tissue. Body fat represents the remaining fat tissue" (Simon, 2005, p. 148). There are standards to determine the levels of body fat that individuals should possess. It is essential to maintain a minimal amount of body fat (percent body fat) for good health, but an excess level as well as a very low body fat level can cause serious health risk (Corbin et al., 2006). This minimal amount of fat is called essential fat and serves for three important functions: (i) insulator to conserve heat, (ii) fuel for the production of energy and, (iii) as padding to cushion internal organs (Going et al., 2013; Simon, 2005).

A growing body of evidence has discussed the exact amount of fat considered essential to normal body functioning; in this sense, boys should possess no less than 5 percent and girls no less than 10 percent. Specifically for girls, a body fat percentage below 10 is one of the criteria used for diagnosing eating disorders, such as anorexia nervosa (Corbin et al., 2006). Nonessential fat is "fat above essential fat levels that accumulates when you take in more calories than you expend. When nonessential fat is accumulated in excess, overfatness or even obesity can occur" (Corbin et al., 2006, p.275).

Although body composition can be considered a component of health-related fitness as well as a component of metabolic fitness, most experts agree that body composition should be categorized as a health-related component of physical fitness (Eisenmann et al., 2013; Ruiz et al, 2011). There are several indicator of body composition, but most fitness tests include either a skinfold test or the BMI as an indicator of this component. Body composition, as well as the other health-related physical fitness components, is related to good health. However, body composition differs to the other parts of health-related physical fitness since it is not a performance measure. Cardiorespiratory fitness, muscular strength and motor fitness can be assessed using some type of movement (e.g. running) or performance (e.g. stretching) and body composition requires no movement or performance. Because of the aforementioned difference, some experts prefer to consider body composition as a component of metabolic fitness (Corbin et al., 2006).

Although the most common indicator of adiposity is BMI, it is important to base decision on more than one indicator in order to avoid misinformation or unrealistic goals. For example, BMI cannot always discriminate the risk of chronic disease at the individual levels. Additionally, being overfat is more important than overweight in making decisions about health. For example, it is possible that individuals who do regular physical activity, they also possess a large muscle mass; these individuals can be high in body weight without being too fat. Another aspect to take into account when measuring weight is the state of hydratation or dehydratation. A person can lose weight merely by losing body water (becoming dehydrated) or gain weight by gaining body water (becoming hydrated). For this reason, it is necessary to assess body composition using several measurements (Cornier et al., 2011; Corbin et al., 2006). In next sections we deeply explain the different methods to assess body composition

Body composition and health

Obesity has increased dramatically in both children and adults in the past twenty years. However, the prevalence varies depending on age, ethnicity, and geographic region. According to recent national surveys, 78 million U.S. adults (more than one-third) are obese. Among children and adolescents aged 2-19 years, more than 5 million girls and ~7 million boys are obese, which is almost 1 out of 5 boys and girls (Ogden, et al., 2012). In Spain, the prevalence of overweight and obesity in youth aged 8-17 year was 26% and 12,6%, respectively; 4 in 10 young people were overweight or obese (Sánchez-Cruz et al., 2013). As such, obesity has been elevated form a secondary to a primary risk factor for heart diseases. A growing body of evidence demonstrates harmful effects of youth obesity and excess adiposity on cardiovascular health (Going et al., 2011; Laurson et al., 2011). The health risk associated with obesity may vary depending on the position of adipose tissue (Cornier et al., 2011). Body fat that is located in the core of the body is referred to as visceral fat. Specifically, visceral fat is located in the abdominal cavity, as opposed to subcutaneous fat, which is located just under the skin. Visceral fat is associated with high blood fat levels as well as other metabolic problems. It is also associated with high incidence of heart attack, increased risk of ischemic stroke, chest pain, certain cancers later in life and early death (Strazzullo et al., 2010; Corbin et al., 2006; Lawlor et al., 2005).

Furthermore, being obese in childhood has implications for obesity in adulthood, and obesity is associated with increased overall mortality and mortality after cardiovascular events (Pischon et al., 2008; Whitaker et al., 1997). For example, those individuals who are moderately overfat have a 40 percent higher than normal risk of shortening life as well as individuals who are classified as severely obese have a 70 percent higher than normal death rate (Corbin et al., 2006). Additionally, youth obesity is associated with mental health problems (i.e. depression and anxiety) and cognitive impairment (Kamijo et al., 2014; Kamijo et al., 2012; Luppino et al., 2010).

Assessment

Estimating body composition can carry out by both laboratory methods (e.g. underwater weighting, total body water, dual-energy X-ray absorptiometry or DXA, and multicomponents models) and field methods (e.g. BMI, circumference, skinfolds and bioelectric impedance). For laboratory methods the standard errors of estimations are smaller (usually between 2 and 3% for percent fat) than for field methods (between 3 and 4%). Although field measures include errors that are higher than those of laboratory methods, field methods tend to be relatively inexpensive measurements that are widely applicable to large populations, especially in the school setting (Cornier et al., 2011; Andersen, 2003). Values of fatness obtained from laboratory methods have been used to establish the accuracy of field methods. Table 8 provides a summary of the effectiveness of field methods in order to a better understanding of the limitations of each method (Lohman et al., 1998).

Table 8. Rating of the validity and objectivity of body composition methods adapted from Lohman et al. (1998). Values ranging from 5= excellent to 1= unacceptable; BMI, body max index.

Method	**Precise**	**Objective**	**Accurate**	**Valid equations**	**Overall rating**
BMI	5	5	1.5	1.5	2
Circumferences	4	4	3	3	3
Skinfold measurement	4	3.5	3.5	3.5	3.5
Bioelectric impedance	4	4	3.5	3.5	3.5

BMI is calculated as body weight in kilograms divided by height in meters squared (kg/m^2). It is considered as one of the most commonly anthropometric measures to assess total body adiposity. Because of its simplicity as a measure and its global acceptance, it has been used in epidemiological studies (Cornier et al., 2011). Although

BMI is more accurate than body weight, there are limitations to the use of BMI alone to assess adiposity, including poor sensitivity in diagnosing excess body fatness (Okorodudu et al., 2010). The total body weigh does not distinguish between lean and fat mass. Thus, individual with normal weight but excess body fat may not be diagnosed as overweight or obese. Conversely, those with high levels of lean body mass may be misclassified as overweight or obese (Cornier et al., 2011).

The Center for Disease and Control and Prevention classifies weight status in youth according BMI percentiles adjusted for age and sex and calculated based on a compilation of national survey data collected in the United States. In youth 2 to 19 years, a BMI between 5th and <85th percentiles is healthy, between 85th and <95th percentiles is overweight, and at or above the 95th percentile is obese (Barlow, 2007). However, for wider international use, cut off points for BMI were obtained by averaging data from Brazil, Great Britain, Hong Kong, Netherlands, Singapore, and United States . The cut off points for overweight and obesity by sex between 2 and 18 years were defined to pass through BMI of 25 and 30 kg/m^2 at age 18 (Cole et al, 2000).

Body circumference has been shown to be a simple and low cost effective way to estimate body fatness. Body circumferences can be assess at several sites: waist, hip, neck, thigh and calf (table 9). Waist has been the most widely accepted site for assessing distribution of body fat. Circumferences are easily measured with a tape while a person is standing and wearing light clothing. One weakness of circumferences is they may misclassify people who have larger muscle mass (Cornier et al., 2011).

Table 9. Locations of body circumference.

Circumference	Location
Waist	The midpoint between the lowest rib and the iliac crest.
Hip	The level of the widest circumference over the buttocks.
Thigh	The right leg, 1 cm below the gluteal line, on the left leg below the gluteal fold, and at mid thigh.
Calf	The maximum circumference of the calf.
Neck	The midway between the midcervical spine and midanterior neck, just below the laryngeal prominence.

Skinfold measurements are a popular method of assessing body composition because they are relatively easy to do and low cost (Cornier et al., 2011). "Body fat is distributed throughout the body. About one-half of the body's fat is located around the various body organs and in the muscles. The other half of the body's fat is located just under the skin, or in skinfolds" (Corbin et al., 2006, p.277). Skinfolds measure the thickness of 2 layers of skin and the underlying subcutaneous fat. The sites to measure skinfolds are described in table 10 and it is possible to estimate body fat by measuring various sites (Jackson and Pollock, 1985). For example early models used the sum of the 7 skinfold measurements (Jackson and Pollock, 1978). Jackson and Pollock (1985) developed an equation for the prediction of body fat from the sum of three skinfold (chest, abdomen and thigh). Slaughter et al. (1988) suggested using the 2-skindfolds model (triceps and subscapular) with specific equations for boys and girls.

Table 10. Locations of skindfold thicknesses.

Skinfold thickness	**Location**
Chest	A diagonal fold taken on the anterior axillary fold as high as possible.
Axilla	A vertical fold taken on the midaxillary line at the level of the xiphoid process.
Triceps	A vertical fold measured on the posterior midline of the upper arm over the triceps muscle halfway between the acromion and the olecranon processes with the elbow extended and relaxed.
Subscapular	A diagonal fold taken on the line coming from the vertebral border 1 to 2 cm below the inferior angle of the scapula.
Abdominal	A vertical fold taken 2 cm lateral to the umbilicus.
Suprailium	A diagonal fold taken above the iliac crest along an imaginary line extended from the anterior axillary line.
Thigh	A vertical fold taken on the anterior aspect of the thigh midway between the hip and the knee joints.

Skinfolds method is one of the most preferable field method to use in lean participants; however to use in obese individuals with large folds or in older participants with loose connective, this measure is less recommendable since it is difficult to obtain reliable and accurate measures (Cornier et al., 2011).

Bioelectric impedance analysis is a favorably technique for accuracy and has overall ranking similar to those of skinfold measurement techniques. The technique takes advantage of the principle that tissues conduct electricity based on their water and dissolved electrolyte content. Electrodes are placed on the body and low doses of current are passed through the skin. Muscle has greater water content and has less resistance to current than fat. The overall amount of resistance and body size are used to predict body fatness. It is important to take measures 3 to 4 hours before a meal since dehydratation can bias the result (Cornier et al., 2011; Corbin et al., 2006).

Bioelectric impedance requires an equipment very easy to use, portable and less expensive than other sophisticated methods such as DEXA. A limitation of the use of bioelectric impedance analysis to assess adiposity is the fact that it provides unreliable information on body fat distribution, however it is more effective than skindfolds to use in obese individuals (Cornier et al., 2011).

Associations of physical activity, physical fitness and body composition with academic performance.

An emerging body of evidence suggests that physical activity, physical fitness and body composition may have an influence on academic performance during childhood and adolescence. We deeply review the associations of each lifestyle-related factor with academic performance in order to identify the possible gaps of these studies, and thus to examine it in the present PhD Thesis.

Physical activity and academic performance

The majority of studies examining associations between physical activity and academic performance in youth relied in self-reported measures of physical activity (Kim and So, 2012; Ress and Sabia, 2010; Kristjanssion et al., 2010; Kantomaa et al., 2010; Coe et al., 2006; Huang et al., 2006; Nelson and Gordon-Larsen, 2006; Dwyer et al., 2001; Daley and Ryan, 2000), which have demonstrated lower validity than objective measures, such as accelerometers (Adamo et al., 2009). There are only four studies that objectively assessed physical activity in relation to academic performance (Booth et al., 2014; Syväoja et al., 2013; LeBlanc et al., 2012; Kwak et al., 2009). Among studies using self-reported measurements of physical activity, findings mainly showed a positive association with academic performance (Kim and So, 2012; Ress and Sabia, 2010; Kristjansson et al., 2010; Coe et al., 2006; Dwyer et al., 2001); few studies found no association between academic performance and self-reported physical activity in youth (Kantomaa et al., 2010; Nelson and Gordon-Larsen, 2006; Daley and Ryan, 2000) and Huang et al. (2006) found a negative association between moderate to vigorous physical activity and academic performance.

Among studies using accelerometry, two studies found null association between physical activity and academic performance in students aged 10 to 12 years (Syväoja et al., 2013; LeBlanc et al., 2012). A study in a small sample of 15- to16-year-old adolescents found that vigorous physical activity was positively associated with academic performance only in girls, which remained after controlling for fitness and maternal education (Kwak et al., 2009). One longitudinal study showed both positive and negative associations between academic indicators and physical activity variables in adolescents (Booth et al., 2014).

As such, it is difficult to draw a conclusion from previous studies using accelerometers due to their contradictory results. Additionally, such studies were solely focused on adolescents. Adolescence is a period involving important psychological and physiological changes; however, the transitions from early childhood to middle childhood and adolescence imply lifestyle changes which might affect physical activity and academic performance. To the best of our knowledge there is no evidence which rely in objectively assessed physical activity focused on both children and adolescents. The association between physical activity and academic performance is of great relevance due to the ongoing debate between health organizations which aim to increase physical activity during the school days and educational institutions which aims to increase time devoted to academic subjects.

The school setting can provide a unique chance to promote physical activity through physical education , which in turn, can help youth to meet the physical activity recommendations (US Department of Health and Human Services, 2008b). However, many schools argue that the more physical activity in the school setting the less time devoted to other academic subjects. Instead of allocating time for physical education and physical activity during the school day, due to the academic pressure, schools attempt to increase academic time for Mathematics, Language or Science to improve grades and standardized tests scores. As a result, physical activity (i.e. physical education, recess, active breaks) is reduced or eliminated during the school day (Centers for Disease Control and Prevention, 2010). The present PhD tests the hypothesis that objectively assessed physical activity might be positively associated with academic performance among children and adolescents.

Maternal physical activity before and during pregnancy and youth's academic performance

A growing body of evidence suggests that maternal prenatal physical activity has both short- (i.e. decreased resting fetal heart rate, increased amniotic fluid levels, increased endothelium-dependent vasodilation) and longer-term benefits (i.e. lower birth weights, increased gestational ages) on the offspring (May et al., 2012; Hopkins et al., 2011; Mattran et al., 2011; Ramirez-Velez et al., 2011; San Juan et al., 2007). Little is known, however, about the effects of maternal physical activity during this period on the offspring's cognitive development (LeMoyne et al., 2012).

Only a few studies have examined the association between maternal physical activity during pregnancy and the offspring's cognitive functioning (Clapp et al., 1999; Clapp et al., 1998; Clapp, 1996). One study showed that five days after their birth, the offspring of the mothers who practiced physical activity during pregnancy had higher scores in the orientation and state regulation subscales of the Brazelton Neonatal Behavioral Assessment Scales (Clapp et al., 1999).

In another study, the offspring of 52 women who exercised were compared with those of 52 control subjects who were similar in terms of multiple prenatal and postnatal variables. They found that at the age of 1 year there were not differences in mental ability between the offspring whose mothers were active during pregnancy with those whose mothers were not active (Clapp et al., 1998). However, in a separate study, the offspring of 20 women who exercised were compared with those of 20 physically active control subjects. This study showed that the 5-year-old children of the active mothers group performed better on tests of general intelligence and oral language (Clapp, 1996).

Such studies used small sample sizes (n<105) and focused on the first years of life (<6 years); thereby long-term effects cannot be elucidated (Clapp et al., 1999; Clapp et al., 1998; Clapp, 1996). Additionally, these studies did not take into account the independent effect of pre-pregnancy physical activity. Interestingly, maternal physical activity before pregnancy might facilitate physical activity during pregnancy and prepare mothers for a healthy pregnancy (Owe et al., 2009). In addition, as women usually do not realize they are pregnant for the first few weeks, when essential fetal processes have already started, physical activity begun during pregnancy may miss the periconceptional period (Chapin et al., 2004). Therefore, practicing physical activity before pregnancy may be at least as important as during pregnancy. To the best of our knowledge, there is no study investigating the association between prenatal physical activity of women and youth academic performance. The present PhD tests the hypothesis that maternal physical activity before and during pregnancy might be positively associated with academic performance in youth aged 6-18 years.

Physical fitness and academic performance

A growing body of evidence suggests physical fitness may play a key role on academic performance in youth (Fedewa and Ahn, 2011; Etnier et al., 1997). The components of physical fitness with a documented potential to improve health are cardiorespiratory fitness, muscular fitness and motor fitness (Ruiz et al., 2011;Ruiz et al., 2009), each of which may have different effects on academic performance. Previous studies examined the association of cardiorespiratory and muscular fitness with academic performance separately for each component (Chen et al., 2013; Coe et al., 2013; Aberg et al., 2009) or by summing the number of fitness tests that youth passed (London and Castrechini, 2011; Chomitz et al., 2009; Grissom, 2005).

Among studies examining each physical fitness components separately, Chen et al. (2013) evaluated the association between fitness change and subsequent academic performance in 669 Taiwanese schoolchildren from 7th grade to 9th grade. Their results showed that improvement in cardiorespiratory fitness, but not muscular endurance or flexibility, was related to greater academic performance. Coe et al. (2013) investigated the relationship of physical fitness with academic performance and determined the influence of socioeconomic status on this association in 1,701 school-aged youth. They found that socioeconomic status was stronger associated with academic performance than all other variables. Additionally, muscular strength and muscular endurance were significantly associated with academic performance in all grades.

Among studies examining the associations by summing the number of fitness tests that youth passed, Chomitz et al. (2009) determined the association between physical fitness and academic performance in school children in fourth, sixth, seventh and eighth grades. Results showed that the number of fitness test passed was related to academic performance. London and Castrechini (2011) examined changes in physical fitness (assessing by Fitnessgram tests) in relation to academic performance in two cohorts of students, from fourth to seventh grade (1325 students) and sixth to ninth grade (1410 students). They found that those students who were fit had higher scores in both Mathematics and English than those who were unfit.

Only two studies jointly examined physical fitness components (Van Dusen et al.,2011; Castelli et al., 2007). Castelli et al. (2007) in a sample of 259 students in third and fifth grades found that field tests of physical fitness were related to academic performance. Specifically, cardiorespiratory fitness was positively associated with academic performance independently of BMI and fitness variables, whereas BMI was inversely related. Van Dusen et al. (2011) examined the associations between standardized mathematics and reading academic performance scores and physical fitness in a larger sample of 254,743 elementary, middle, and high school children and adolescents. Findings showed that physical fitness was strongly related to academic performance. Cardiorespiratory fitness showed a dose-response association with academic performance independent of other socio-demographic and fitness variables. The association appeared to peak in late middle to early high school. However, these two studies did not include motor fitness (Haapala, 2013).

To the best of our knowledge, there is no study investigating the independent and combined influence of these three components of physical fitness (cardiorespiratory, muscular and motor fitness) on academic performance (Haapala, 2013). Since these three physical fitness components are highly associated each other (Lubans et al., 2010), it is important to differentiate which physical fitness components are important for academic performance. The present PhD tests the hypothesis that each physical fitness component might be both independently and combined associated with academic performance in youth.

Body composition and academic performance

On one hand, a growing body of literature suggests that low birth weight may play a negative role in cognitive development (Kormos et al., 2013). It is likely poor neurodevelopmental outcomes of low birth weight infants may result from either perinatal morbidity or postnatal growth and development (Franz et al., 2009), which in turn, affect academic performance at school age (Zhang et al., 2013; Breslau et al., 2001; Seidman et al., 2000; Strauss, 2000).

For example, Seidman et al. (2000) evaluated the associations of three prenatal and perinatal complications (low birth weight, probable hypoxicischemic complications, and chronic hypoxia) with three neuropsychological measures (academic achievement skills, verbal-conceptual abilities, and perceptual-motor abilities) in 11,889 children at age 7. Their findings showed that all three measures of prenatal and perinatal complications were significantly associated with lower neuropsychological performance. Specifically, low birth weight had the strongest association with neuropsychological performance.

Strauss (2000) determined the long-term functional outcome of small for gestational age infants in a cohort of 14,189 full-term infants. Results showed that infants who were born small for gestational age had significant differences in academic performance and professional attainment later in life compared with those who born at normal birth weight.

Breslau et al. (2001) examined the extent to which deficits in academic performance in low birth weight children at age 11 are explained by deficits in cognitive abilities at school entry. The findings suggested that most of the low birth weight children deficits in academic achievement at age 11 could be eliminated by eliminating differences in cognitive abilities at age 6. A recent study explored the associations between perinatal brain injury, visual motor function and academic performance in 1104 low birth weight infants. Results showed that low birth weight infants with history of perinatal brain injury may have poor academic performance later in life (Zhang et al., 2013).

On the other hand, obesity might have a detrimental effect on academic performance during childhood and adolescence (Datar et al., 2004; Castelli et al., 2007; Sabia, 2007; Kamijo et al., 2012; Liang et al., 2013). These studies have focused on different ages and using different measures for assessing body composition and academic performance. For example, Datar et al. (2004) examined the association between overweight children and academic performance in 11,192 kindergartens. Their findings showed that overweight was significant (unadjusted) associated with worse academic performance. However, in adjusted models, differences in test scores by overweight status at the beginning of kindergarten and the end of first grade were explained by other individual characteristics, including parental education and the home environment. Sabia (2007) examined the relationship between adolescent obesity and academic achievement on a sample of 5,129 students aged 14-17 years. Findings showed a negative relationship between BMI and GPA for white girls. However, for nonwhite girls, and for boys, there was no evidence of a causal association between body weight and academic performance.

Kamijo et al. (2012) evaluated the association between adiposity (BMI and fat mass) and cognition (cognitive control and academic performance) in 126 preadolescent children aged 7-9 years. Their findings suggested that the negative relationship between BMI and cognitive function was selectively observed for tasks requiring greater amounts of cognitive control in preadolescent children. Additionally, higher BMI was associated with poorer academic achievement scores. Castelli et al. (2007) in a sample of 259 students in third and fifth grades found that BMI was negatively associated with total academic performance, reading performance and mathematics performance.

Although there is a growing body of evidence on the associations of obesity and low birth weight with academic performance, to our knowledge, to date there is no study investigating the independent and combined influence of these two aspects of body composition on academic performance. The present PhD tests the hypothesis that neonatal and current body composition might be both independently and combined associated with academic performance in youth.

VIII. AIMS

Overall:

The overall aim of this PhD Thesis was to analyze the associations of physical activity, physical fitness and body composition with academic performance in children and adolescents.

Specific:

I. To systematically review the evidence on the associations between physical activity and cognition by differentiating between academic and cognitive performance measures and to identify potential factors (i.e. sex, physical activity intensity levels and psychological variables) that may modify the association between physical activity and cognition **(Paper I).**

II. To examine the association between objectively measured physical activity and academic performance in youth **(Paper II).**

III. To examine the association between mother physical activity before and during pregnancy and youth academic performance **(Paper III).**

IV. To examine the independent and combined associations of the components of physical fitness with academic performance among youth **(Paper IV).**

V. To examine the independent and combined associations between neonatal and current body composition with academic performance among youth **(Paper V).**

IX. METHODS

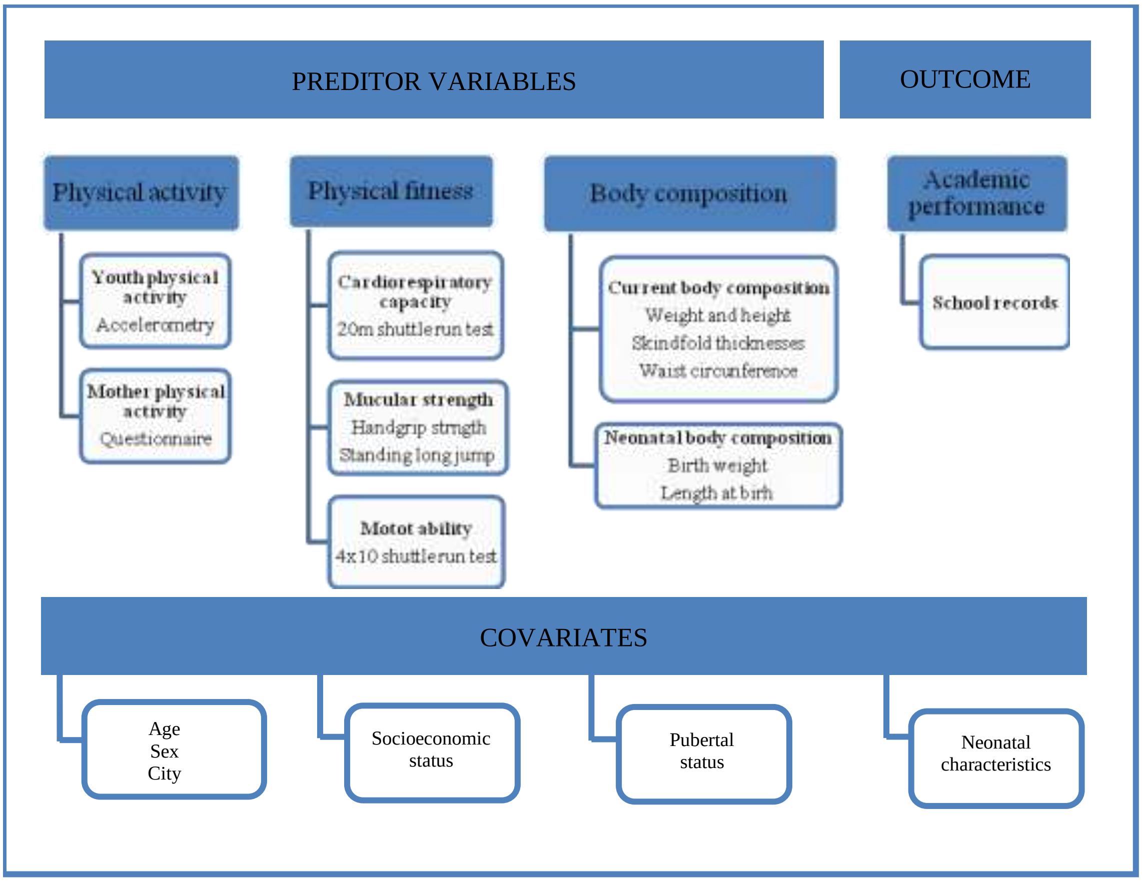
Participants

The current PhD Thesis is based on data from the UP&DOWN study (Follow-UP in schoolchildren AND in adolescents with DOWN syndrome: psycho-environmental and genetic determinants of physical activity and its impact on fitness, cardiovascular diseases, inflammatory biomarkers and mental health; www.upanddownstudy.com). This study was supported by the DEP 2010-21662-C04-00 grant from the National Plan for Research, Development and Innovation (R+D+i) MICINN. This is a 3-year longitudinal study designed to assess the impact over time of physical activity and sedentary behaviors on health indicators as well as to identify the psycho-environmental and genetic determinants of physical activity in a convenience sample of Spanish children and adolescents.

For the recruitment, 24 primary schools from Cadiz and 46 high schools from Madrid were contacted through letter, of which 23 primary schools and 22 high schools were interested in participating. Four high schools were excluded for logistical reason and, finally 23 primary schools and 18 high schools were enrolled in the UP&DOWN study. All students for 1th and 4th grades in primary schools and for 7th and 10th grades in high schools were invited to participate in this study. Informative meetings with parents and adolescents were carried out in primary schools and high schools, respectively. At these meetings written information was provided detailing the project' aims and how they would be contributing to the study. Data collection was undertaken from September 2011 to June 2012.

A total of 2225 youth (aged 6-18 years) participated in the UP&DOWN study, specifically, 1188 children from Cadiz and 1037 adolescents from Madrid. The sample for the present PhD Thesis varied in each paper (from 1557 to 2044 participants). Youth with complete data on the dependent and independent variables were included in each paper. The main variables used in the present PhD Thesis are summarized in table 11.

Table 11. Main variables for the present PhD Thesis



Academic performance assessment

Academic performance was assessed through schools records at the end of academic year. GPA score was standardized by calculating a single average for the examinable subjects in each grade. Academic performance was based on four indicators: individual grades for the core subjects (Mathematics and Language), an average of Mathematics and Language, and GPA score. For analytic purposes, individual letter grades were converted to numeric data: A = 5, B = 4, C = 3, D = 2, F = 1 (Coe et al., 2012; Coe et al., 2006; Dwyer et al., 2001).

Physical activity assessment

Youth physical activity

Objectively measured physical activity was obtained by the ActiGraph accelerometer models GT1M, GT3X and GT3X+ (Actigraph TM, LLC, Pensacola, FL, US) (figure 12). The GT1M is a small and lightweight uniaxial accelerometer (3.8 x 3.7 x 1.8 cm, 27 g) designed to detect vertical accelerations ranging in magnitude from 0.05 to 2.00 g with a frequency response of 0.25-2.50 Hz. The epoch (i.e. the amount of time over which activity counts are integrated and recorded) duration was set at 2-second. The GT3X and GT3X+ are triaxial accelerometers (4.6 x 3.3 x 1.5cm, 19 g) capable of measuring accelerations from -6 to 6g with a frequency response of 0.25 to 2.50 Hz. The epoch duration was set at 30 Hz and their data were subsequently converted into 2-second epoch in the download. Recent studies confirmed that there is strong agreement among the three models (Robusto and Trost, 2013; Vanhelst et al., 2012). The ActiGraph accelerometers have been widely calibrated for youth in laboratory and free-living conditions (Freedson et al., 2005).

Figure 12. ActiGraph accelerometer model GT3X

Each participant wore the accelerometer at the lower back for 7 consecutive days (Figure 13), which is a reasonable wear time standard to obtain reliable estimation of usual activity for all ages (Ward et al, 2005). Participants must remove the accelerometer during sleep hours and water-based activities. The inclusion criterion was an activity monitor recording of at least 10 hours per day for 3 days (Cain et al., 2013).

Figure 13. Participant wearing an accelerometer.

The data were downloaded and analyzed using the ActiLife software (v.6.6.2 Actigraph TM, Pensacola, FL, US). Before analyses, data were reintegrated into a 10-second epoch. Non-wear time was identified by summing the number of consecutive zero counts per minute. For this study, the non-wear algorithm was defined as a period of 60 minutes of zero counts and an allowance for up to 2 consecutive minutes (<100 counts per minute) with the up/downstream 30 minutes consecutive of zero counts for detection of artifactual movements (Cain et al., 2013; Choi et al., 2011).

Physical activity was estimated using cut-points of 2000 and 4000 counts per minutes for moderate physical activity and vigorous physical activity, respectively. These cut- points to define the intensity categories are similar to those used in previous studies with European children and adolescents (Martinez-Gomez et al., 2010; Ekelund et al., 2007). The physical activity variables included in the present PhD Thesis were count per minutes as a measure of overall amount of physical activity, and time spent at moderate physical activity, vigorous physical activity and moderate to vigorous physical activity intensities (min/day) (figure 14).

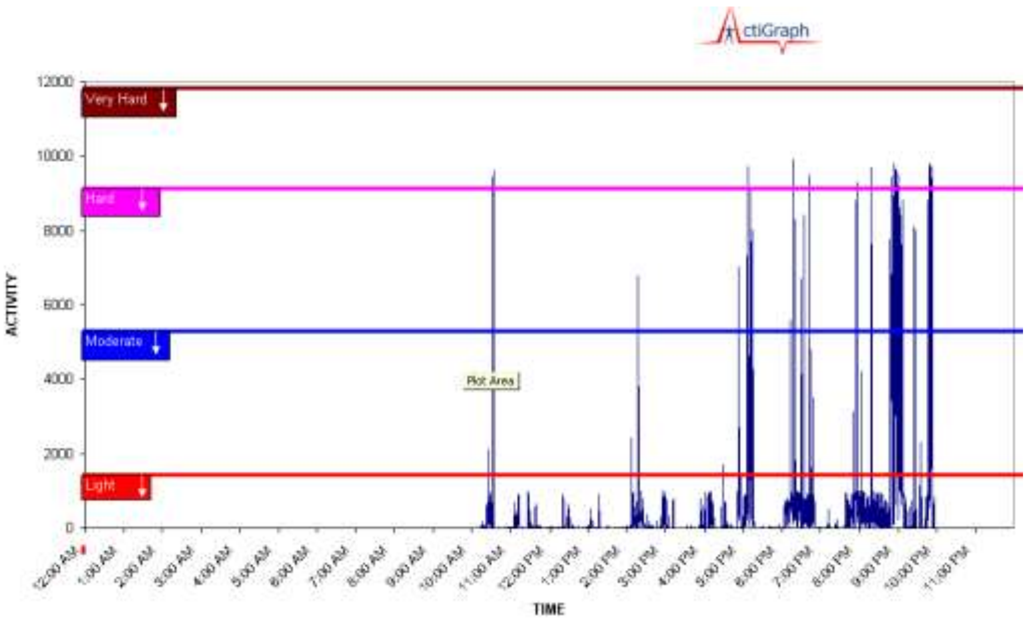


Figure 14. Examples of physical activity variables derived from accelerometry data in one participant.

Maternal physical activity before and during pregnancy

Mothers self-reported their physical activity practice before and during pregnancy. They answered the following questions: "Do you practice physical activity before pregnancy?", and "Do you practice physical activity during pregnancy?". The possible answers were yes or no.

Physical fitness assessment

Physical fitness was assessed following the ALPHA Health-Related Fitness Test Battery for youth. The ALPHA fitness test battery was developed to provide a set of valid, reliable, feasible and safe field-based fitness tests for the assessment of health-related physical fitness in children and adolescents, to be used in the public health monitoring system in a comparable way within the European Union (Ruiz et al., 2011; Castro-Piñero et al.,2008). The main physical fitness variables included in the present PhD Thesis were the number of stage completed in the 20-m SRT as measure of cardiorespiratory fitness; a single standardized muscular fitness score computed from the maximum handgrip strength and the standing long jump tests; and the time in seconds^{-1} completed in the 4 × 10-m SRT as measure of motor fitness.

Cardiorespiratory fitness

Cardiorespiratory fitness was assessed by the 20-m SRT. Participants were required to run between two lines 20-m apart, while keeping pace with a pre-recorded audio CD. The initial speed was 8.5 km/h, which was increased by 0.5 km/h each minute (1 minute equal to 1 stage). Participants were instructed to run in a straight line, to pivot on completing a shuttle (20-m), and to pace themselves in accordance with the audio signals. The test was finished when the participant failed to reach the end lines concurrently with the audio signals on two consecutive occasions. Otherwise, the test ended when participant stops because of fatigue. The test was performed once. The score was the number of stages completed (Ortega et al., 2008a). The number of stages was transformed to maximal oxygen consumption (VO_2max, ml/kg/min) using the Lèger equation (Lèger et al., 1988):

Lèger equation: Predicted $_{VO2max}$ = 31.025 + (3.238 x (8 + 0.5 x last stage completed)) - (3.248 x age)+ (0.1536 x (8 + 0.5 x last stage completed) x age).

In addition, according to the predicted VO_2max, youth were classified by the Fitnessgram standards based on the Healthy Fitness Zone (table 12) for the individual´s sex and age (The Cooper Institute, 2010).

Table 12. The Healthy Fitness Zones (The Cooper Institute, 2010).

Cardiorespiratory capacity *The Healthy fitness zone (VO_2max, ml/kg/min)*		
	Females	*Males*
Age		
5	VO_2max standards not available for children ages 5-9.	
6		
7		
8		
9		
10	≥40.2	≥40.2
11	≥40.2	≥40.2
12	≥40.1	≥40.3
13	≥39.7	≥41.1
14	≥39.4	≥42.5
15	≥39.1	≥43.6
16	≥38.9	≥44.1
17	≥38.8	≥44.2
17+	≥38.6	≥44.3

Muscular fitness

Muscular fitness was assessed using maximum handgrip strength and the standing long jump (lower limb explosive strength) tests. A hand dynamometer with an adjustable grip was used (TKK 5101 Grip D, Takey, Tokyo Japan) for the handgrip strength test (figure 15).

Figure 15. Hand dynamometer (TKK 5101 Grip D, Takey, Tokyo Japan)

The grip-span of the dynamometer was adjusted according to the hand size of the youth (Ruiz et al., 2006). Hand size was measured in right hand at maximal width and by measuring the distance separating distal extremes of the first and fifth digits. Participants put their hands over the ruler-table to measure the optimal grip span. There were one ruler-table for children aged 6-12 years and another for adolescents aged 13-18 years (figure 16). The precision of the measure was 0.5 cm. The results of hand size were rounded to the nearest whole centimeter.

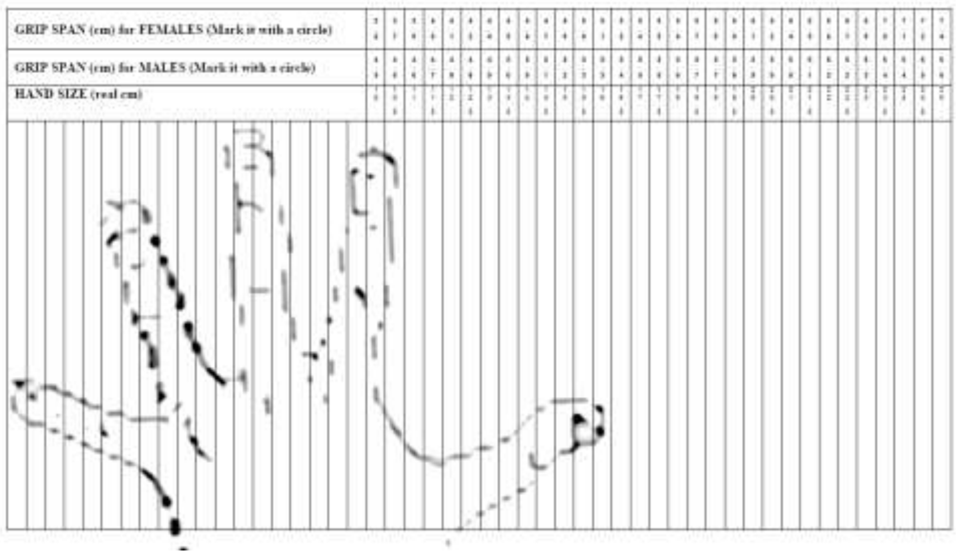


Figure 16. Ruler-table for adolescents (13-18 years) (www.thealphaproject.eu).

The participants were stood and squeezed the dynamometer continuously for at least 2 seconds, alternatively with right and left hand. The elbow must be in full extension and avoiding contacting with any other part of the body with the dynamometer, except the hand being measured (España-Romero et al., 2010). The test was performed twice allowing a short rest between measures and the maximum score for each hand was recorded in kilograms. The average score of the left and right hands was calculated.

Standing long jump test was performed from a starting position behind a line, standing with feet approximately shoulder's width apart. The youth jumped as far forward as possible, landing with feet together. The test was performed twice and the longer distance was recorded in centimeters (Ortega et al., 2008a). A single muscular fitness score was computed from the two muscular tests. The individual score of each test was standardized as follows: Z-standardized value = (value − mean)/SD. The muscular fitness score was calculated as the mean of the two standardized scores (Martinez-Gomez et al., 2011).

Motor fitness

Motor fitness was assessed with the 4 × 10-m SRT of speed-of-movement, agility and coordination. Participants were required to run back and forth twice between two lines 10-m apart (figure 17). Youth were instructed to run as fast as possible and every time they cross any of the lines, they should pick up (the first time) or exchange (second and third time) a sponge that has earlier been placed behind the lines. The test stops when participants cross the finishing line with one foot. The test was performed twice and the fastest time was recorded in seconds (Ortega et al., 2008a). Since the motor fitness score is inversely related to high physical fitness, it was first multiplied by −1. Additionally, the motor fitness score was dichotomized at the sex- and age-specific 75th percentile, identifying youth with clustered risk as those above this value;

participants were also categorized using the sex- and age-specific 1 SD. Previous studies have used these cut points to match the prevalence of clustering risk factors (Artero et al., 2011b; Andersen et al., 2006).

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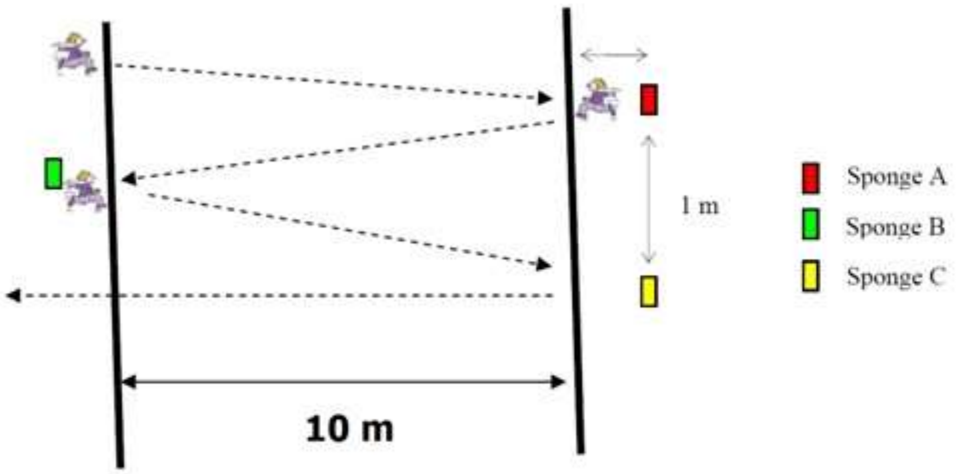

Figure 17. The 4 × 10-m shuttle-run test (www.thealphaproject.eu).

Body composition assessment

Current body composition

Current body composition was objectively assessed following the ALPHA Health-related Fitness Test Battery for youth (Ruiz et al., 2011). The complete set of body composition measurements was performed twice and averages were recorded. The current body composition variables included in the present PhD were BMI as kg/m^2, body fat as percentage and waist circumference in centimeters.

Height and weight, as measures of *body size,* were assessed with participants having bare feet and wearing light underclothes. Height was measured in the Frankfort plane to the nearest 1 mm and weight to the nearest 0.05 kg using a standard beam balance with a stadiometer (SECA 701 and SECA 861SECA, Hamburg, Germany). Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m^2). Overweight (including obese) youth were classified according to international age- and sex-specific BMI cut-offs (table 13) proposed by Cole et al.(2000).

Skinfold thicknesses were measured at the non-dominant side of the body to the nearest 0.1 mm with a Holtain caliper (figure 18) at the triceps and subscapular sites.

Figure 18. Holtain caliper.

Table 13. Age- and sex-specific BMI cut-offs (Cole et al., 2000).

	Body mass index			
	Overweight (25 kg/m^2)		*Obesity (30 kg/m^2)*	
	Girls	*Boys*	*Girls*	*Boys*
Age				
6.0	17.3	17.6	19.7	19.8
6.5	17.5	17.7	20.1	20.2
7.0	17.8	17.9	20.5	20.6
7.5	18.0	18.2	21.0	21.1
8.0	18.3	18.4	21.6	21.6
8.5	18.7	18.8	22.2	22.2
9.0	19.1	19.1	22.8	22.8
9.5	19.5	19.5	23.5	23.4
10.0	19.9	19.8	24.1	24.0
10.5	20.3	20.2	24.8	24.6
11.0	20.7	20.6	25.4	25.1
11.5	21.2	20.9	26.1	25.6
12.0	21.7	21.2	26.7	26.0
12.5	22.1	21.6	27.2	26.4
13.0	22.6	21.9	27.8	26.8
13.5	23.0	22.3	28.2	27.2
14.0	23.3	22.6	28.6	27.6
14.5	23.7	23.0	28.9	28.0
15.0	23.9	23.3	29.1	28.3
15.5	24.2	23.6	29.3	28.6
16.0	24.4	23.9	29.4	28.9
16.5	24.5	24.2	29.6	29.1
17.0	24.7	24.5	29.7	29.4
17.5	24.8	24.7	29.8	29.7
18.0	25.0	25.0	30.0	30.0

(i) The triceps skinfold (figure 19_S1) was picked up about 1 cm in vertical above the halfway between the acromion process (the most lateral bony protuberance of the back of the shoulder) and the olecranon (the bony structure that stands out when the elbow is bent), at the right angle to the "neck" of the fold.

(ii) The subscapular skinfold (figure 19_S2) was picked up about 1 cm on diagonal below the tip of the scapula, at an angle of 45º to the horizontal plane in the natural cleavage lines of the skin. Participants stood comfortably erect, with the upper extremities relaxed at the sides of the body to locate the site. For some youth, particularly for those who were obese, gentle placement of the participant's arm behind the back aided to easily identify the site.

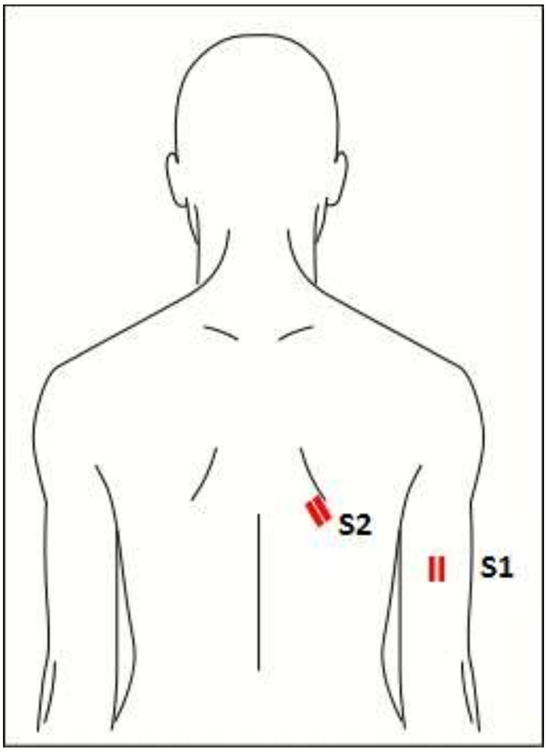

Figure 19. Skinfold thicknesses at triceps (S1) and subscapular (S2) sites (http://www.dh.aist.go.jp/en/)

Body fat percentage was calculated from triceps and subscapular skinfold thicknesses using Slaughter's equations (Table 14). Fat free mass, in kilograms, was estimated by subtracting fat mass (body fat percentage multiplied by weight) from total body weight (Slaughter et al., 1988).

Table 14. Slaughter's equations (Slaughter et al., 1988).

Equations to estimate body fat percentage (BF%)
Females
Females when triceps + subscapular ≤ 35 mm
BF% = 1.33 (triceps + subscapular) − 0.013 (triceps +subscapular)^2 − 2.5
Females when triceps + subscapular > 35 mm
BF% = 0.546 (triceps + subscapular) + 9.7
Males
Males when triceps + subscapular ≤ 35 mm
Pre-puberal (Tanner stage 1)
BF% = 1.21 (triceps + subscapular) − 0.008 (triceps +subscapular)^2 − 1.7
Puberal (Tanner stage 2,3, and 4)
BF% = 1.21 (triceps +subscapular) − 0.008 (triceps +subscapular)^2 − 3.4
Post-puberal(Tanner stage 5)
BF% = 1.21 (triceps +subscapular) − 0.008 (triceps +subscapular)^2 − 5.6
Males when triceps + subscapular > 35 mm
BF% = 0.783 (triceps +subscapular) + 1.6

Waist circumference was measured with a non-elastic tape (figure 20) in a horizontal plane, at the level of the natural waist, which is the narrowest part of the torso from a front view. Participants stood erect with the abdomen relaxed, the arms at the sides and the feet together. The measurement was taken at the end of a gentle expiration without the tape compressing the skin. For some youth, especially for those who were obese, the measurement was performed in the midpoint between the superior iliac spine and the costal edge in the midaxillary line, because of identifying of their waist circumference was difficult.

Figure 20. Non-elastic tape

Neonatal body composition

Birth weight in kilograms and length at birth in centimeters were self-reported by parents. Two neonatal body compositions indexes were calculated. BMI at birth was calculated as birth weight in kilograms divided by birth length in meters squared (kg/m^2). Ponderal index was computed as birth weight in kilograms divided by birth length in meters cubed (kg/m^3). Additionally, low birth weight participants were defined as those with birth weight $\leq$2.5 kg (Johnson and Breslau, 2000; McCormick et al., 1992).

Covariates

Covariates or confounders are defined as those variables that can affect the relationship between the dependent variable and other independent variables. The main covariates of the present PhD Thesis were age (years), sex (boys/girls), city (Cadiz/Madrid), socioeconomic status, pubertal status and neonatal characteristics

Socioeconomic status

The socioeconomic status was defined by the maternal educational level reported as elementary school, middle school, high school and university. Answers were dichotomized as below university education and university education (Klein-Platat et al., 2003; Gnavi et al., 2000).

Pubertal status

Pubertal development was self-reported according to the five established Tanner stages. Each stage describes breast and pubic hair development in girls and genital and pubic hair development in boys (Tanner and Whitehouse, 1976).

Neonatal characteristics

Gestational age and trimester of birth were self-reported by parents. Gestational age at time of delivery was reported as a continuous variable (weeks). The trimester of birth was defined by month of birth date in four categories: first (January-March), second (April-June), third (July-September) and fourth (October- December) trimester.

Statistical analyses

Descriptive statistics are presented as means (SD) or percentages. Differences between sexes were tested by one-way analysis of variance and Chi-squared tests for continuous and nominal variables, respectively. All the variables were checked for normality of distribution before the analyses, and square root transformations were applied for those variables that were not normally distributed. Interaction factors (i.e., sex x main exposures and age x main exposures) were considered to evaluate whether age and sex modified the associations of physical activity, physical fitness and body composition with academic performance. When interactions were found, all analyses were performed separately for boys and girls or/and children and adolescents, otherwise all data were pulled together.

The associations of the predictor variables (physical activity, physical fitness and body composition) with academic performance were analyzed by linear regression using separate models to examine the independent association between exposures and outcomes. These models were mainly adjusted for age, sex, city and maternal education. Additionally , models were controlling for pubertal status, gestational age and trimester of birth; as well as when the predictor variables were not modeled as the main exposures, the analyses were also adjusted for them.

For the combined analyses, the predictor variables were dichotomized according to specific cut-points and youth were subsequently classified in groups according to the number of risk factors. Differences in academic performance with the number of risk factors were tested by one-way analysis of covariance with Bonferroni adjustment for potential confounders. Analyses were performed using the IBM SPSS Statistics 18.0 for Windows and the level of significance was set at $p < 0.05$.

Ethical aspects

The study was conducted according to the ethical standards established in the 1961 Declaration of Helsinki (reviewed in Seoul, Republic of Korea in October 2008), the EEC Good Clinical Practice recommendations (document 111/3976/88, July 1990) and the current Spanish legislation regulating clinical and biomedical research in humans, personal data protection and bioethics (Royal Decree 561/1993 on clinical trials and 14/2007, 3rd July, for Biomedical Research). The UP&DOWN study protocols were approved by the Ethics Committee of the Hospital Puerta de Hierro (Madrid, Spain), the Bioethics Committee of the National Research Council (Madrid, Spain), and the Ethics Committee for Research Involving Humans Participants at University of Cadiz (Spain). Before participation in the UP&DOWN Study, parents and school supervisors were informed by letter about the study. Written parental consent and youth' assent were obtained. The data collected as well as any documents generated were numerically coded for anonymity and protection from unauthorized use by people not involved in the study.

Methodological limitations

The present PhD Thesis has several limitations which should be highlighted:

Firstly, the cross-sectional design does not allow drawing conclusions on the causal directions of the associations. Thus, longitudinal studies with the present sample should carry out to provide insights on the causal-effect of exposures (physical activity, physical fitness and body composition) on academic performance.

Secondly, the fact that it was undertaken a convenience sample, although relatively large and heterogeneous sample of children and adolescents, limits its generalizability across the population, so findings must be interpreted with caution.

Finally, although grades were extracted from the school records and are socially valid measures of academic performance, they have potential limitations of bias, so studies are recommended using standardized achievement tests and measures of brain function.

X. RESULTS AND DISCUSSION

Overall results and discussion

The results and discussion of the present PhD Thesis are shown as a compilation of scientific papers. They are enclosed in the form they have been published or submitted:

- Paper I. Physical activity and cognition in adolescents. A systematic review. **J Sci Med Sport.**
- Paper II. Objectively measured physical activity and academic performance in youth. The UP & DOWN Study. **Acta Paediatr.**
- Paper III. Maternal physical activity before and during the prenatal period and the offspring's academic performance in youth. The UP&DOWN Study. **Am J Hum Biol.**
- Paper IV. Independent and combined influence of the components of physical fitness on academic performance in youth. The UP & DOWN Study. **J Pediatr.**
- Paper V. Independent and combined influence of neonatal and current body composition on academic performance in youth. The UP & DOWN Study**. Pediatric Obesity.**

In general, a healthy lifestyle, being physically fit and maintaining a healthy body composition during childhood and adolescence may be crucial for a better academic performance. This PhD Thesis also highlights the association between maternal physical activity before and during pregnancy and youth's academic performance. The overall results and discussions of the present PhD Thesis are summarized as follows:

Physical activity and cognition in adolescents:

There is evidence of a positive relationship of self-reported physical activity with both cognitive and academic performance in adolescents. Cognitive performance seems to be associated with vigorous physical activity (Travlos, 2010; Coe et al., 2006), while academic performance seems to be related to general physical activity, mainly in girls (So, 2012; Morales et al., 2011; Fox et al., 2010; Kwak et al., 2009; Coe et al., 2006). In this sense, different intensity levels of physical activity apparently have distinctive effects on cognitive and academic performance. It is possible to speculate that this could be due to a different ‘‘threshold’’ level of physical activity intensity being necessary to produce beneficial effects on cognitive and academic performance. Vigorous physical activity intensity levels seem to produce this beneficial effect on cognitive performance, but whether this intensity threshold is necessary for detectable effects on academic performance is not clear. Therefore, further prospective and experimental studies in adolescents are required to examine the optimal level of physical activity (intensity and quantity), assessing sedentary-, light-, moderate-, and vigorous-intensity levels of physical activity, which may confer improved academic performance

In addition, some psychological factors, as self-esteem and depression, may mediate the association between physical activity and academic performance in adolescents. As well as, the moderating effect of sex suggested that there was an association between more time spent in physical activity and higher cognitive (Martínez-Gómez et al., 2011) or academic (Fox et al., 2010; Rees and Sabia, 2010; Kwak et al., 2009) performance more frequently in adolescent girls than in adolescent boys. This tendency could be explained by the dose-response effect (Martínez-Gómez et al., 2011); adolescent boys are more active than girls (Armstrong and Welsman, 2006), therefore, the stimulus achieved from lower levels of measured physical activity may not be sufficient in boys to produce the same physiological effect that was seen in girls, who were generally less active (Carlson et al., 2008). Thus, future studies should routinely analyze the moderating effect of sex on the association between physical activity and cognition as well as clarify the psychological factor that may mediate this relationship using reliable and valid measurement instruments.

Objectively measured physical activity and academic perfromance in youth.

Objectively measured physical activity may influence academic performance during both childhood and adolescence independently of neonatal variables, fatness and fitness; however this association, albeit negatively significant, the extent to which physical activity influences academic performance was very weak. These results may be indicative of more physically active youth spending less time on studying. Another explanation could be that those youth who had higher academic performance spend the most time studying. However, *post hoc* analyses in a subsample (n=1217; 49%girls) of the present study showed that there were no significant interaction between time spent studying and physical activity at different intensities in relation to academic variables ($p > 0.1$), so time spent studying was not a moderator of such association.

Few studies have investigated the associations between objectively measured physical activity and academic performance (Booth et al., 2014; Syväoja et al., 2013; LeBlanc et al., 2012; Kwak et al., 2009), even though it is important to investigate this association because physical activity provided plasticity and flexibility to the brain, which in turn may have a positive influence on academic performance (Romeo and McEwen, 2006). Two of these studies found null association between physical activity and academic performance in students aged 10 to 12 years (Syväoja et al., 2013; LeBlanc et al., 2012). A study in a small sample of 15- to16-year-old adolescents found that vigorous physical activity was positively associated with academic performance only in girls (Kwak et al., 2009), and one longitudinal study showed both positive and negative associations between academic indicators and physical activity variables in adolescents (Booth et al., 2014).

The inconsistent findings in studies using accelerometers may be explained not only through the variations in samples and methods (e.g. the age range, accelerometer procedures), but also multiple other factors may contribute to such contradictory evidence. First, academic performance was differently assessed through grades (Syväoja et al., 2013; Kwak et al., 2009) and standardized tests (Booth et al., 2014; LeBlanc et al., 2012). Our academic indicators were also grades, however grades were related not only to academic skills, but also to teacher perception, the quality and quantity of academic teaching, family background and environment, and even cultural factors. Therefore, the academic indicator used (e.g. grades, standardized tests, cognitive skills tests) may be important to avoid bias (Seyfried, 1998).

Second, several confounding factors included in our study were not always taken into account in the previous studies, making comparisons difficult. For example, birth weight and gestational age, variables broadly related to academic and cognitive performance (Breslau et al., 2001), were only included in one study (Booth et al., 2014). Fitness was incorporated as a covariate in only one other study (Kwak et al., 2009). According to Etnier et al (2006), fitness may mediate the relationship between physical activity and academic performance. We found that fitness was related to physical activity and to academic performance, therefore, fitness might indeed be mediated such association in our results. However, our findings and those from Kwak et al.(2009) showed there was no mediated effect between physical activity an academic performance through fitness. Lastly, it is possible that the volume of daily physical activity at different intensities is not a good indicator of the quality of physical activity related to academic performance. Future studies should investigate the association between objectively measured physical activity in specific periods (e.g. recess, physical education, active breaks) in relation to academic performance.

Maternal physical activity before and during pregnancy and youth' academic performance.

Maternal physical activity before and during pregnancy was related to youth's academic performance in boys, but not in girls. Importantly, these findings were independent of potential confounders, specifically physical activity, fitness, current BMI, and birth weight, which might modify the aforementioned associations due to their relationship with both outcomes and exposures (Van Deutekon et al., 2013; Touwslager et al., 2013).

These encouraging findings may have several explanations. First, women are unaware they are pregnant for the first few weeks, when essential fetal processes have already started. Organogenesis (i.e. the formation and differentiation of organs during embryonic development) extends from the second to the eighth week of gestation. This period is extremely vulnerable, so environmental factors may produce particularly strong influences for embryonic growth, resulting in positive or negative health consequences later in life (Mook-Kanamori et al., 2010; Chapin et al., 2004). Maternal stress early in pregnancy may influence hippocampal dependent learning and memory (Muller and Bale, 2007) as well as increase the risk of schizophrenia in the offspring males (Khashan et al., 2008).

A woman's active lifestyle before pregnancy may provide substantial health benefits for women before pregnancy and reduce the risk for an adverse pregnancy (US Dept of Health and Human Services, 2008b); moreover, this woman's active lifestyle is the strongest predictor of her lifestyle during pregnancy (Owe et al., 2009). For example, in the present study, 74% of women who were physically active or inactive before pregnancy maintained their lifestyle during pregnancy. Consequently, women who practice physical activity before pregnancy may be more likely to continue being active during pregnancy, contributing to a greater benefit for youth academic performance later in life.

Experimental studies in rats showed that physical activity during gestation in pregnant mothers can increase hippocampal BDNF mRNA (messenger ribonucleic acid) expression in postnatal pups (Parnpiansil, et al., 2003) and can improve objective recognition memory in adult male offspring (Robinson and Bucci, 2014). It has been previously shown that some maternally derived growth factors (e.g. BDNF) cross the placenta and are active in the fetus (Gilmore et al., 2003). Importantly, BDNF is implicated in brain plasticity, which in turn, may enhance cognitive function (Cotman and Engesser-Cesa, 2002). Thus, the offspring's cognitive and academic performance might be enhanced.

Another interesting finding was that boys whose mothers maintained the physical activity practice during pregnancy scored higher in all academic indicators than those whose mothers continued being inactive or became active. It seems that being physically active just during the pregnancy period could be insufficient to lead to beneficial effects in the offspring's academic performance. Pregnancy lasts 9 months, a short period in which the effects of maternal physical activity on fetus might not have a benefit if the organism was not previously prepared. Regular physical activity enhances important aspects of the maternal physiologic adaptations to pregnancy in ways that are also fetoprotective (Clapp, 1994). However, although we examined maternal physical activity before and during pregnancy separately, it is difficult to determine the independent biological relevance of the two exposure periods. Thus, it is not clear whether physical activity before pregnancy or during pregnancy contributes to the offspring's academic performance, or whether both are required.

Lastly, the reasons explaining why maternal physical activity before and during the prenatal period might improve academic performance only in the offspring boys cannot be elucidated, yet some candidate mechanisms should be explored. Maternal stressors may impact brain development, especially the hippocampus and hypothalamus, and cognitive abilities in the offspring in a sex-dependent manner (Charil et al., 2010; Bale, 2011). For example, the effect of maternal stress on placental gene expression in mice were found only in the male offspring; male placentas exhibited increases in the expression of several genes important in growth and development such as insulinlike growth factor-binding protein 1 (IGFBP-1) (Mueller and Bale, 2008). An elevation in placental IGFBP-1 could potentially decrease the available growth factors during critical developmental periods, and plays a role in fetal programming and brain development, which were specific to males (Myatt, 2006). In humans, the influence of maternal depression during pregnancy on offspring postnatal anxiety development was detected only in boys (Gerardin et al., 2011). The majority of evidence was focused on negative stressors; however, the offspring outcomes varied depending upon the stressor involved (Brunton and Russell, 2010). As such, physical activity might be a positive stressor for cognitive functioning, as it augments brain plasticity by facilitating adaptive and protective processes through the mediation of BDNF and insulin-like growth factor-1 (Dishman et al., 2006; Cotman and Berchtold, 2002).

Components of physical fitness and academic peroformance in youth.

Cardiorespiratory fitness and motor fitness, both independently and combined, were related to academic performance in youth, independent of potential confounders, including fatness. In contrast, muscular fitness was not associated with academic performance independently of the other two physical fitness components. Present results contribute to the current knowledge by suggesting that the interdependent relationships of cardiorespiratory and motor fitness may have a beneficial influence on academic performance in youth.

Several mechanisms have been proposed to explain the association of cardiorespiratory fitness and motor fitness with academic performance. First, cardiorespiratory fitness induces angiogenesis in the motor cortex and increases blood flow which could also affect cognitive performance. Second, aerobic physical activity increases BDNF levels (Adkins et al., 2006) and is related to higher P3 event-related brain potential amplitude and lower P3 latency, which reflects a better ability to modulate neuroelectric indices of cognitive control (Pointifex et al., 2011). Third, motor fitness induce syntaptogenesis, increases in BDNF and tyrosine kinase receptors, and reorganization of movement representations within the motor cortex. Lasty, the spinal cord has a central role in the final common pathway for motor behavior. Thus, this set of coordinated neuronal changes related to motor fitness might support improved cognitive development (Adkins et al., 2006).

In the present PhD Thesis, we also found that cardiorespiratory fitness was even more strongly associated with academic performance than fatness indicators. These findings implied that cardiorespiratory fitness may be more important to academic performance than fatness per se, consistent with a prior study of Texas school children (Welk et la., 2010). Likewise, motor fitness was strongly associated with academic performance independently of fatness indicators. The association of academic performance with physical fitness was stronger for motor fitness than for cardiorespiratory fitness. Therefore motor fitness may have even greater importance for academic performance than cardiorespiratory fitness. One explanation that might partially account for the higher association of motor fitness with academic performance may be the mental processing involving in motor fitness. Motor tasks that represent different challenges may lead to more improvement in academic performance (Chaddock et a., 2010). Another possibility could be the relevance of fine motor skills in some cognitive abilities, for example in reading or writing, which require visual-control, and visual and manual coordination (Pangelinan et a., 2011). Additionally, common brain structures are used for both motor and cognitive performance, with co-activation of the neocerebellum and dorsolateral prefrontal cortex during cognitive activity (Diamond et al., 2000).

Collectively, present findings suggested the possible combined association of having low cardiorespiratory fitness and motor fitness on all academic performance indicators. Youth having 2 fitness risk factors had lower academic performance compared to those with either 1 or 0 risk factors. However, the low prevalence of youth with both risk factors (5%) precludes drawing any firm conclusions. The lack of studies analyzing the interdependent and combined influence of these fitness risk factors in youth prevents the possibility of comparing present results with others. More research is warranted examining both the independent and combined effect of cardiorespiratory and motor fitness on academic performance in young people.

Evidence regarding muscular fitness and academic performance remains equivocal. Several cross-sectional studies have reported muscular strength was related to academic performance in school-aged youth (Bass et al., 2013; Coe et al., 2013; Van Dusen et al., 2011; Eveland-Sayers et al., 2009; Dwyer et al., 2001). In contrast, other research in children and adolescents demonstrated that changes in musclar fitness were not associated with academic performance (Chen et a., 2013; Edwards et al., 2011; Castelli et al., 2007) or cognitive performance (Ruiz et al., 2010; Aberg et al., 2009). A longitudinal study in a large sample of 15-to 18-year-olds showed no relationship between muscular fitness and cognitive performance (Aberg et al., 2009). This inconsistency may be due to the aforementioned studies not adjusting the association between muscular strength and cognition for other components of physical fitness. In the present PhD Thesis, muscular fitness was notably associated with cardiorespiratory fitness (r=0.43) and motor fitness (r=0.57), and, present results showed the relationship between muscular fitness and academic performance disappeared after controlling for cardiorespiratory fitness and motor fitness. This suggests the other two components of physical fitness might be more important to cognition than muscular fitness.

Neonatal and current body composition and academic performance in youth.

Neonatal and current body composition, both independently and combined, were associated with academic performance in youth. Neonatal body composition was related to academic performance in boys, independent of potential confounders, including BMI; whereas current body composition was related to academic performance in both boys and girls, independent of potential confounders, including birth weight. In addition, the combined adverse effects of low birth weight and current overweight on academic performance were observed in both boys and girls. These novel results contribute to a growing body of evidence by suggesting that an unhealthy body composition across the lifespan may have a negative effect on academic performance in youth.

Experimental evidence in neuroscience supports the present observed association between academic performance and multiple body composition indicators at birth and throughout the whole course of life (Liang et a., 2013; Espy et al., 2009). Brain development is highly susceptible to the consequences of preterm birth (Pitcher et al., 2012). A recent study using magnetic resonance imaging showed that low birth weight was associated with smaller brain volumes (Clark et al., 2013). Others neuroimaging studies indicated that obesity was associated with detectable structural differences in the brain in youth as well as in younger adults (Reinert et al., 2013; Pannacciulli et al., 2006) . Therefore, unhealthy body composition from birth through adolescence might induce an important impairment that hampers learning and academic performance.

Present findings showed that birth weight was positively associated with academic performance, thus low birth weight youth had lower academic performance. However, this influence showed a sex effect, and only low birth weight boys had lower values in all of the academic indicators, independent of current BMI. To our knowledge, almost all studies that examined associations between birth weight and cognitive outcomes in youth showed significant associations with boys and girls together (Zhang et al., 2013;Tsou et al., 2008;Seidman et al., 2000; Strauss, 2000). The sex-specific effect observed in our study concurs with that in other studies (Phua et al., 2012; Dannemiller , 2004, Matte et al., 2001;Johnson and Breslau, 2000). Johnson and Breslau (2000) showed an increased risk for learning disabilities in low birth weight boys but not in girls. Other studies demonstrated the larger effects of low birth weight for boys on general intelligence (Matte et al., 2001), visual attention (Dannemiller , 2004) and executive function (Phua et al., 2012).

The factors underlying this interaction between sex and birth weight remain to be determined. A possible explanation might be that the sex of the fetus may produce different responses to variations in maternal nutrition (Forsen et al., 1999). It is likely that pregnant woman carrying a male embryo had higher energy intake than those pregnant woman carrying a female embryo and as such, maternal nutrition might influence fetal growth

(Tamimi et al., 2003). In our findings, boys were 100g heavier than girls and gestational age did not differ between boys and girls. Thus, boys grew more rapidly in prenatal development, and as such, they may be more susceptible to the influences of nutritional variation during gestation (Dannemiller , 2004). It is reasonable to suppose that a similar nutritional mechanism might influence the prenatal development of the brain, which may explain why variations in birth weight among boys are more strongly related to later cognitive outcomes than among girls. Future studies should clarify the mechanisms that induce the sex effect found in our study.

Another interesitng finding from the currentPhD Thesis showed that the inverse association of current BMI, waist circumference and body fat percentage with academic performance were stronger for girls than boys, after controlling for potential confounders including birth weight and maternal education. A possible explanation is that self-esteem of girls may be more adversely affected by overweight, which in turn, may affect academic performance (Sabia, 2007). There are several studies showing that current body composition was negatively associated with academic performance (Kamijo et al., 2012; Sigfúsdóttir et al., 2010; Castelli et al., 2007; Sabia, 2007; Datar et al., 2004); however just one study included birth weight as a covariate (Datar et al., 2004). Moreover, these studies only assessed current body composition through BMI. Paradoxically, BMI may be the least accurate indicator of body composition, because the height and weight relationship varies dramatically during growth, which might underestimate or confuse the association between current body composition and academic performance during childhood and adolescence (Kamijo et al., 2012). Kamijo *et al.* (2012) supplemented BMI with more accurate measures of adiposity (i.e. whole body fat and abdominal fat mass measured using dual X-ray absorptiometry), and indicated that higher levels of central adiposity were more robustly related to lower cognition in children aged 7 to 9 years . Similarly, the present work supplemented BMI with waist circumference and body fat percentage and showed BMI and waist circumference were more robustly associated with academic performance than body fat percentage. It is possible that variations between studies are due to the different methods used to asses current body composition and academic performance as well as the specific age ranges within studies. Thus, further longitudinal studies in a larger sample of youth are necessary to examine the relationship between current body composition and academic performance independently of birth weight, using more accurate measures.

In the analyses of combined effects we observed a negative association of being both low birth weight and overweight on all academic performance indicators for boys, and on GPA score for girls. Youth having the 2 risk factors had lower academic performance compared to those with either 1 or 0 risk factors. These findings suggested the possible combined effect of being low birth weight and overweight on academic performance. However, the low prevalence of youth with both risk factors (3% of boys and 2% of girls) precludes drawing any firm conclusions. The lack of studies analyzing the combined effect of these risk factors in youth prevents the possibility of comparing our results with others. More research is warranted examining both the individual and the combined effect of neonatal and current body composition on academic performance in young people

I

PHYSICAL ACTIVITY AND COGNITION IN ADOLESCENTS. A SYSTEMATIC REVIEW.

Esteban-Cornejo I, Tejero-González CM, Sallis JF, Veiga OL.

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Physical activity and cognition in adolescents: A systematic review

Irene Esteban-Cornejo[a], MSc. ;Carlos Mª Tejero-Gonzalez[a], PhD., James F. Sallis[b], PhD; Oscar L Veiga[a], PhD.

[a] Department of Physical Education, Sports and Human Movement, Autonomous University of Madrid, Madrid, Spain.

[b] Department of Family and Preventive Medicine, University California, San Diego, San Diego, CA, USA

Address for correspondence:

Irene Esteban Cornejo

Department of Physical Education, Sports and Human Movement.

Universidad Autónoma de Madrid

Ctra de Colmenar km 15, 28049 Madrid

Tf: + 34 91 497 21 16 Fax：+34 91 497 84 80

Email: irene.esteban@uam.es

ABSTRACT

Objective: The purpose of this report is to perform a systematic review of the evidence on the associations between physical activity and cognition by differentiating between academic and cognitive performance measures. Second-generation questions regarding potential mediators or moderators (i.e. sex, age and psychological variables) of this relationship were also examined.

Design: Systematic review.

Methods: Studies were identified from searches in PubMed, Sportdiscus and ERIC databases from 2000 through 2013. The search process was carried out by two independent researchers.

Results: A total of 20 articles met the inclusion criteria, 2 of them analyzed both cognitive and academic performance in relation to physical activity. Four articles (18%) found no association between physical activity and academic performance, 11 (50%) found positive association and one showed negative association (5%). Five articles (23%) found positive association between physical activity and cognitive performance and one showed negative association (5%). The findings of these studies show that cognitive performance is associated with vigorous physical activity and that academic performance is related to general physical activity, but mainly in girls. Results of the review also indicate that type of activity and some psychological factors (i.e. self-esteem, depression) could mediate the association between physical activity and academic performance.

Conclusions: Results of the review support that physical activity is associated with cognition, but more research is needed to clarify the role of sex, intensity and type of physical activity and some psychological variables of this association.

Keywords: physical activity, cognition, cognitive performance, academic performance, adolescents, systematic review.

INTRODUCTION

Cognition, a wide term to refer to cognitive and academic performance, is a mental function involved in gaining knowledge and comprehension. A high cognition has been identified as a positive marker of health[1]. Likewise variables associated with cognition have been used to assess psychological health of school aged individuals[26].Specifically, adolescence is a critical stage for cognition[2], and cognition in adolescents may be an important predictor of adult health[5,6]. For example, poor cognition during adolescence has been associated with higher morbidity and mortality[8,10], anxiety disorders[11], depression[14], psychological distress[15,16], coronary heart disease[18] and some cancers later in life[19]. High cognition is linked to positive psychological-related variables such as self-esteem and self-concept[20]. A healthy lifestyle during adolescence may be crucial for better cognition[21].

Habitual physical activity may be a key determinant of cognition during adolescence[22-26], which is the period of life with the greatest decline in physical activity levels across the lifetime[27-29]. A growing body of literature suggests that physical activity has a clear influence on cognition measures such as concentration, working memory, inhibition and classroom behavior during these ages, aspects that are the foundation for academic abilities[7,9,32]. By contrast, some studies have also shown contradictory evidence regarding the link between physical activity and cognition[33,34]. This contradictory evidence might be due to the fact that academic performance is arbitrarily assessed by academic and cognitive measures. According to conceptualization proposed by Keeley[33], cognitive performance is mainly related to psycho-physiological shifts in cerebral function, whereas academic performance is associated not only with cognitive performance, but also with family background and environment, teacher perception, and the quality and quantity of academic teaching[35]. Thus, some studies showed that academic and cognitive measures were moderately correlated with each other in adolescents[3.] Therefore, it is possible that separately investigating academic and cognitive performance in adolescents would help to clarify their association with physical activity.

Two previous reviews in school-children aged 5-18 years collectively reported the positive effect of physical activity on cognition[23,24]. However, our revision is focused specifically on studies in adolescents. Brain plasticity changes with age[2] and there is some evidence that physical activity stimulates some factors involved in brain plasticity, such as brain-derived neurotrophic factor

(BDNF)[36]. Age could therefore be a critical factor in the relationship between physical activity and cognition.

This review also analyzes the selected studies aimed at identifying potential moderating (i.e. interaction variable that affects the direction and/or strength of the relationship between exposures and outcomes) or mediating (i.e. intervening variable that is on the causal pathway between exposures and outcomes) variables in the link between physical activity and cognition in this age group such as cognition assessment, sex, physical activity intensity level, and various psychological variables. To our knowledge, there is no review that takes these possible moderator or mediator interactions into account. Finally, our review also expands on the previous research by including studies up to 2013.

To conclude, the purpose of this report is to systematically review the evidence of association between physical activity and cognition by differentiating between academic and cognitive performance measures. In addition, this paper also reviews potential mediators and moderators (i.e. sex, age and psychological variables) that may modify the association between physical activity and cognition.

METHODS

Selection of the literature

During March 2014, a comprehensive search of three databases of literature (PubMed, Sportdiscus and ERIC) from 2000 through 2013 was undertaken (Table 1). The principal search terms were as follows: (1) "academic performance" (cognitive performance, academic achievement, performance at school, and academic outcomes), (2) “physical activity” (physical education, sport, athletic participation and exercise behavior), and (3) “adolescent” (children, school-age youth, student, school and childhood).

Table 1: Search strategy in databases

Database	Search Strategy	Limits
PubMed	("physical activity" OR "physical education" OR sport OR athletic participation OR exercise behavior) AND ("academic performance" OR academic achievement OR performance "at" school OR academic outcomes OR cognitive performance) AND (adolescent OR children OR student OR childhood OR school-age youth OR school) NOT 2013[dp]	Publication date from 2000/01/01 to 2012/12/31. Species: Humans. Ages: Adolescent: 13–18 years.
SportDiscus (EBSCO)	(TI ("physical activity" OR "physical education" OR sport OR athletic participation OR exercise behavior)) AND (AB (academic performance OR academic achievement OR performance at school OR academic outcomes OR cognitive performance)) AND (AB (adolescent OR children OR student OR childhood OR school-age youth OR school))	Publication date from 2000/01/01 to 2012/12/31. Document type: Journal article
ERIC (EBSCO)	(TI ("physical activity" OR "physical education" OR sport OR athletic participation OR exercise behavior)) AND (AB (academic performance OR academic achievement OR performance at school OR academic outcomes OR cognitive performance)) AND (AB (adolescent OR children OR student OR childhood OR school-age youth OR school))	Publication date from 2000/01/01 to 2012/12/31, Document type: Journal article

Inclusion criteria

A predetermined set of inclusion criteria was used to select papers for this systematic review. Each study had to meet the following criteria:

(1) It included a population that has to overlap with high-school-aged adolescents between 13 and 18 years. This adolescent age range is based on the U.S. National Institutes of Health's National Library of Medicine (*age criterion*).

(2) It reported a cross-sectional, longitudinal or interventional study design (*study design criterion)*.

(3) It aimed to determine the association of physical activity with academic or cognitive performance (*relationship criterion)*.

(4) It described at least one academic or cognitive performance measurement (*measurement criterion)*.

(5) It was an article published in English or Spanish (*language criterion)*.

Data extraction and reliability

A standard data extraction template was developed to extract the main details for every eligible study in terms of author, title, objective, sample size, country, design, physical activity measurement, cognition measurement and results about the relationship between physical activity and cognition. These first details were used as a basis of the evidence tables. Finally, the search process was carried out by both researchers (I.E. and CM.T.). A single researcher (I.E.) examined every title and abstract to identify a potentially relevant paper for review. In case of uncertainty, a second researcher (CM.T.) checked the selection process.

RESULTS

Search results

The flow of citations through the systematic review process is shown in Figure 1. A total of 608 results were returned. After removing 47 duplicates, this search retrieved 561 unique citations. A total of 436 articles were rejected at title and abstract level. Subsequently, full-text copies of 125 potentially relevant citations were obtained and reviewed. Of these 125 papers, a total of 106 articles were excluded. Therefore, 19 unique citations passed the eligibility criteria and were included in the systematic review. After review of their reference lists, one further paper that satisfied the inclusion criteria was added.

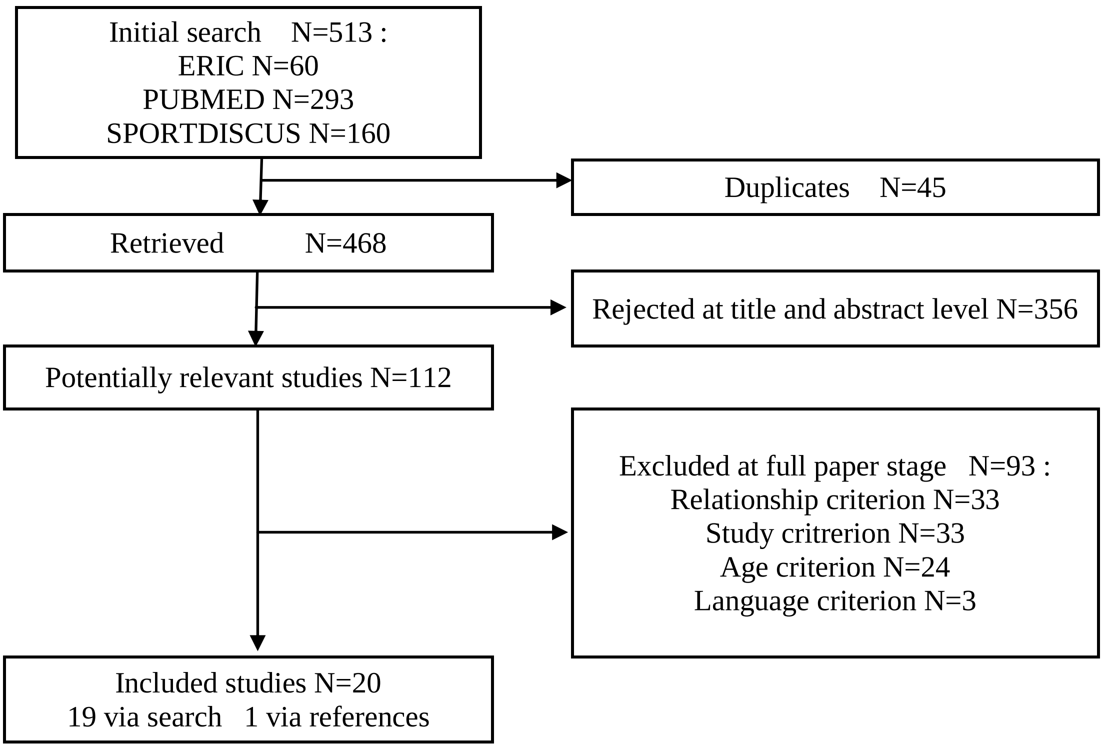

Figure 1. Papers Selection Process

General

This review examines the findings of 20 studies [21,34,37-54] that explored the relationship between physical activity and cognition. Of these, 75% of studies[21,37-50] were of cross-sectional design, 15% were longitudinal studies[34,51,52] and 10% were interventional studies [53,54]. The sample size varied from 48 participants[47] to 75 066 participants[49,50]. Information about all the studies is chronologically presented in Table 2 (supplementary material).

Physical activity measurement

Physical activity patterns were examined using self-report measures among 19 studies[21,34,37-47,49-54], six of these studies showed the validity of the self-reported physical activity questionnaires[40,44,46,47,51,53], and only one study used objective measure of physical activity[48]. Five studies assessed physical activity taking into account only athletic participation[21,34,42,52] (i.e., individual sport activities and team athletics) or physical education[49]. Seven studies[43-47,50,54] used questionnaires without recalling each day specifically, to estimate weekly physical activity. One of these studies[45] also examined self-reported active commuting to school. Seven studies[37-41,51,53] used physical activity recall questionnaires reporting in detail each day.

Cognition measurement

Cognitive performance measurements.

Cognitive performance measurements took into account a large variety of skills, including reading, mathematics, reasoning, science and social studies. Two studies[21,45] used the SRA (Science research associates) Test of Educational Ability to assess verbal, numeric and reasoning abilities. Two studies[34,53] examined cognitive performance using a standardized test score. One of them [34] used composite tests in reading, math, science, and history and the other study[53] used the Terra Nova test, which consisted of multiple assessments of reading or language arts, mathematics, science, and social studies. Two studies[46,54] used a narrow variety of skills. One of them [46] selected two subtests from the BADYG (battery of differential and general aptitude) to assess oral and math skills, and the other one[54] used a 2-min mathematics task performing simple additions to evaluate numeric ability.

Academic performance measurements.

Academic performance was assessed using self-reported grades or grades reported by schools. Nine studies[39,41-44,49-52] used self-reported grades, six[34,37,38,47,48,53] used grades reported by schools, and one study[40] used both kinds of reporting. Six studies[34,38-40,47,48] used all subjects (including Physical Education), two studies[37,51] used English, Math and Science. History was added to these subjects in one study [52] and World Studies in another[53]. English, Math and Danish (or Swedish or Norwegian), were used in one study[44], and these together with Icelandic in another [41] .One study [43] used Math and Natural Sciences (such as biology, chemistry and physics), and included Finnish and general subjects (such as History and Religion). However, three studies[42,49,50] did not specify any subjects. Math was the unique common subject included in all studies.

Relationship between physical activity and cognition

Collectively, 70% of studies examined the relationship of physical activity with academic performance[34,37-44,47-53], whereas 30% of studies examined the relationship between physical activity and cognitive performance[21,34,45,46,53,54]. From all studies, 20% found no associations[37,39,43,51], while 80% found association, 70% of associations positive[21,31,34,38,42,44-50,52-54] and 10% negative[34,40].

Physical activity and cognitive performance.

Results across six studies showed significant associations. Five studies[21,45,46,53,54] determined positive associations and one longitudinal study[34] reported negative associations. This longitudinal study[34] reported sport participation among twelfth-grade students remained negative for cognitive performance after controlling for potential confounders including academic performance in previous grades. Moreover, when the type of sport participation is defined (i.e. individual vs. team sport), team sport participation remained negative for cognitive performance, whereas there was no association with participation in individual sports.

The two intervention studies[53,54] specifically analyzed the association between timing of physical education classes and cognitive performance. One of them[54] noted that the timing of physical education classes during the school day (i.e. morning *vs.* afternoon) may influence the results. Attending the 1st, 3rd, and 5th hour of the daily physical education classes was related to a significantly higher cognitive performance, while attending the 6th-hour class was associated with a decrease of cognitive performance. However, the other study[53] found that cognitive performance was not influenced by the timing across the year of physical education class enrollment (i.e., first or second semester). The same study showed[53] that increases in cognitive performance were associated with vigorous activity, but not with moderate physical activity. Likewise, Travlos[54] demonstrated that intense physical education classes had beneficial effects on youth cognitive performance. Nevertheless, these studies[53,54] conducted no analysis by sex.

By contrast, three studies[21,45,46] examined the moderating effect of sex. One study[45] found that active commuting to school was associated with better cognitive performance in girls but not in boys. However, the other two studies[21, 46] found no differences by sex in results regarding participation in extracurricular physical activities. One of them[46] also examined the moderating effect of age and demonstrated that participation in extracurricular physical activity was related to better cognitive performance at younger ages.

Physical activity and academic performance.

The relationship of physical activity and academic performance showed effects of different magnitudes. Four studies[37,39,43,51] found no association. One study[40] showed a negative association between moderate to vigorous physical activity (MVPA) and academic performance, independent of adiposity, and eleven studies[34,38,41,42,44,47-50,52,53] showed positive associations.

Four studies[42,48,50,53] found different associations of physical activity intensity levels with academic performance, most of them identifying differences by sex. One study[42] found that after adjusting for sociodemographic variables, there was an association between performing more hours of MVPA and a higher grade point average (GPA) for both genders, but after adjusting for sports team participation, this association was significant only for high school girls. Another study[50] found that there was a relationship of academic performance with vigorous physical activity only in boys and with moderate physical activity in both boys and girls. Likewise, other study[48] showed that vigorous physical activity was the only intensity level correlated with academic achievement, but solely in girls. This study also showed no mediating effect between physical activity and academic performance through fitness[48]. However, Coe *et al*.[53] noted that increases in academic performance were associated with vigorous activity and not with moderate physical activity, however, analysis by sex was not performed in this study.

Three studies[34,38,49] reported different associations between mode of physical activity and academic performance. One of them[34] determined that sport participation in twelfth-grade students was positively associated with academic performance after controlling for potential confounders including ratings at 8th and 10th grades. Moreover, team and extramural sport participation was greater associated with academic performance than individual and intramural sport participation. Another study[38] showed that the relationship between academic performance and minutes of weekly activity was weaker when time spent travelling to school was added to the total minutes of physical activity (i.e. physical education, school sport, and other activities). The other one[49] identified that attending three or more physical education classes per week was positively correlated with improved school performance. Moreover, Morales *et al*.[47] examined energy expenditure and showed greater academic performance for the "high" and "moderate" active groups than the "low" active group.

The moderating effect of sex on the association between physical activity and academic performance was specifically reported in four studies[34,38,49,52]. One study[52] showed that sports participation was associated with increases in GPA for girls, but not for boys. On the other hand, three studies[34,38,49] found no differences in their results by sex. Two studies[41,44] showed that some psychological factors (self-esteem, depression) seemed to mediate the association between physical activity and academic achievement. One of them[44] found physical activity was directly and positively related to academic achievement, but to a lesser extent when self-esteem was included. In addition, the other study[41] reported that the association between physical activity and academic performance become non significant when depressed mood and self-esteem were included in the model.

DISCUSSION

The current review summarizes all studies from 2000 to 2013 that met the defined inclusion criteria, regardless of study characteristics. Results from the studies included in the present systematic review suggested that physical activity is positively related to academic and cognitive performance in high school students. Nevertheless, only two are intervention studies[53,54] and three are longitudinal studies[34,51,52].

Regarding to measurements, physical activity was assessed through self-reported questionnaires in the most of studies, few studies showed the validity of these questionnaires [40,44,46,47,51,53] and only one used objective measures of physical activity[48]. This fact indicated, and as previous reviews[23,24] pointed out, the necessity for future studies to assess physical activity objectively by using accelerometers. On the other hand, reviewed studies used either cognitive tests or grades to assess cognitive or academic performance respectively, and only two studies [34,53] used both measures. A study in a large sample of adolescents showed that academic and cognitive measures were moderately correlated with each other (*r*s ranged from .27 to .57, $p < .001$)[3.]Nevertheless, there was no agreement on an adequate method to assess cognition in the school context, nor regarding the use of school subjects to assess academic performance. Math was seen as the only included subject common to all studies. It is necessary, therefore, to further explore the association between physical activity and different types of cognition measures in future studies.

Most of the studies (approximately the 75%)[21,34,38,41,42,44-50,52-54] in the present review showed significant positive associations between physical activity and cognition, which allows drawing consistent conclusion in the association. According to Sallis *et al.* strong evidence of an association exists when 60% of studies find significant associations in the same direction[30]. Five studies reported this association with cognitive performance and eleven studies with academic performance and only two studies found a significant negative association of physical activity with cognitive[34] or academic performance[40]. Four studies found no association[37,39,43,51]. Several mechanisms have been suggested to explain a beneficial effect of physical activity on cognition[55]. The effect of exercise on the brain could be the result of several factors including increased flow of blood[56,57] and oxygen to the brain[57], or higher levels of chemicals and increased activity-dependent synaptic plasticity[58].

One study conducted with young male adults as subjects[4] reported that vigorous activity can increase brain-derived neurotrophic factor (BDNF) and catecholamines (dopamine and epinephrine). Findings from intervention studies in adolescents reported that vigorous physical activity was the only intensity level that significantly correlated with cognitive performance[53,54]. By contrast, academic performance was associated not only with vigorous physical activity[48,50,53], but also with MVPA[42,47], moderate-intensity [50] and light-intensity activity[47]. In this sense, different intensity levels of physical activity apparently have distinctive effects on cognitive and academic performance. It is possible to speculate that this could be due to a different ''threshold'' level of physical activity intensity being necessary to produce beneficial effects on cognitive and academic performance. Vigorous physical activity intensity levels seem to produce this beneficial effect on cognitive performance, but whether this intensity threshold is necessary for detectable effects on academic performance is not clear. Therefore, further prospective and experimental studies in adolescents are required to examine the optimal level of physical activity (intensity and quantity), assessing sedentary-, light-, moderate-, and vigorous-intensity levels of physical activity, which may confer improved academic performance.

Moreover, physical education or sport participation provided a portion of students' daily physical activity, and these were positively related to cognitive[21,45] and academic performance[34,49,52]. However, these physical activities do not cover the complete range of physical activity in which youth are involved [31] (e.g. recess, lunch time or active commuting to school), and may confound the link of physical activity with cognitive and academic performance. For example, active commuting to school was associated with a better cognitive performance independent of extracurricular physical activity in girls[45]. By contrast, academic performance was more weakly related to physical activity when time actively commuting to school was added to the total minutes of physical activity[38].

Overall, the 50% of reviewed studies that observed associations between physical activity and cognition in adolescents showed no analysis by sex,[41,44,47,53,54], or found no differences in outcomes by sex[21,34,38,46,49]. These findings were in line with a previous review from the US Department of Health and Human Services[23], which focused on the association between school-based physical activity and academic performance. Our review expands the previous review by taking into account the moderating effect of several factors (e.g. sex and age) on the association of physical activity, with both academic and cognitive performance. Specifically, the sex-effect suggested that there was an association between more time spent in physical activity and higher cognitive[45] or academic[42,48,52] performance more frequently in adolescent girls than in adolescent boys. There was just one study which found effects favoring boys over girls, and solely in vigorous physical activity[50]. This tendency could be explained by the dose-response effect[45]; adolescent boys are more active than girls[12],therefore, the stimulus achieved from lower levels of measured physical activity may not be sufficient in boys to produce the same physiological effect that was seen in girls, who were generally less active[13]. Based on the results drawn in our review, future studies should routinely analyze the moderating effect of sex on the association between physical activity and cognition.

Additionally, our review identified two other potential factors that may mediate the association between physical activity and cognition: self-esteem[44,41] and depression[41]. Specifically, the mediating effect of self-esteem seemed to play a key role in the relationship between physical activity and academic performance. Other sets of factors proposed in previous research that might mediate the association of physical activity with cognitive and academic performance were socioeconomic status (i.e. parental education and family structure) [41,48] , absenteeism[41], cardiorespiratory fitness and body mass index[21]. Consequently, these and other potential confounders such as genetic factors, fetal nutrition, cultural factors and physical activity in the school setting (recess activity, lunchtime activity or physical education) should be taken into account in future studies.

The strength of this review came from the extensive literature search using well defined inclusion criteria to make advanced comparisons of the findings of full-text articles which passed the eligibility criteria. The examination of findings by academic and cognitive performance separately, the exploring of results by sex and the inclusion of studies conducted in different parts of the world, served to broaden the generalizability of our findings. Our study, however, has some limitations. Studies were not ranked or weighted, and as a result, findings from studies with weaker designs and smaller sample sizes were given no less importance than findings from studies with more rigorous research designs and larger sample sizes. The lack of assessment of bias, within and across studies. The fact that it was identified only two studies that included self-esteem and depression, which limits the possibility to draw conclusion regarding their mediating effect of the associations.

CONCLUSION

In conclusion, our findings support evidence of a positive relationship of physical activity with both cognitive and academic performance (approximately the 75% of studies supporting a positive association) [17, 33]. Cognitive performance seems to be associated with vigorous physical activity[53, 54], while academic performance seems to be related to general physical activity, mainly in adolescent girls[42,48,52]. In addition, some psychological factors, such as self-esteem and depression, could be involved in the association between physical activity and academic performance[41,44]. However, more intervention and prospective studies are warranted in order to clarify the mechanisms that affect this relationship in adolescents. Moreover, it would be of interest to investigate whether the optimal level of physical activity which may confer improved cognition in adolescents could be different for cognitive and academic performance.

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Table 2. Description of the included studies reporting on the relationship between physical activity and cognition in high-school adolescents

Author	Title	Objective	Sample/ age/ county/design	Physical activity (PA) measurement	Cognition measurement	Results of physical activity and cognition
Daley &Ryan,[37] 2000	Academic performance and participation in physical activity by secondary school adolescents.	To examine PA in relation to previous AP of boys and girls in secondary school.	232/ 13-16 years/ UK/ Cross sectional	Self-reported PA participation (frequency and duration) during a typical week.	Most recent examination scores in English, Math, and Science.	No significant correlations were found. However, PA participation (frequency and duration) was weakly negatively correlated to English scores (13-16 age adolescents) and Science scores (adolescents aged 16).
Dwyer *et al.*,[38] 2001	Relation of academic performance to physical activity and fitness in children.	To examine the association of scholastic performance with PA and fitness of children.	7,961/ 7-15 years/ Australia/ Cross sectional	Self-reported minutes of PA (travelling to school, physical education, school sport, other activities) during the last week and usual PA at recess and lunchtime.	School rating of each subject on a 5-point scale. (from 'poor=1' to 'excellent=5').	The ratings were significantly correlated with questionnaire measures of PA. The association with lunchtime activity and minutes of PA (physical education, school sport, other activities) was stronger than with recess activity. The relationship with minutes of weekly activity was weaker when time spent travelling to school was added to the total.
Linder,[39] 2002	The physical activity participation-academic performance relationship revisited: perceived and actual performance and the effect of banding (academic tracking).	To examine the relationship between AP and PA participation using objective measures of scholastic achievement**,** and the effect of banding (academic tracking)	1,447/13-17 years/Hong Kong / Cross sectional	Type, frequency and duration of sport and PA by questionnaire.	Self-reported academic potential on a 6-point scale (from 'far below average' to 'good').	Positive relationship between AP and PA participation time in boys. No association between PA and AP among girls. Positive link between PA participation and band level of students (school grouping based on primary academic achievement).

Marsh & Kleitman,[34] 2003	School athletic participation: mostly gain with little pain	To examine athletic participation effects on growth and change during high school.	4,250/ 13-14 years/ US/ Longitudinal	Self-reported number of athletic activities (intramural and extramural or team and individual sports) during Grades 10 and 12.	Standardized test in Reading, Math, Science, and History and grades reported by school.	Total athletic participation was positively correlated with AP at Grade 12. However, the effect of total athletic participation was negative for cognitive performance.
Coe et al[53], 2006	Effect of physical education and activity levels on academic achievement in children.	To determine the effect of physical education class enrollment and PA on academic achievement in middle school children.	214/ 10-13 years/ US / Interventional	Self-reported frequency (number of 30-min time blocks) and intensity (≥3.0-5.99 or ≥6.0 METs) of PA in the 3 previous days by the 3-D Physical Activity Recall (3DPAR). * Intervention: classes of physical education every day of the week for 55 min during either first or second semesters.	Grades of Mathematics, Science, English, and World Studies in each semester. -Terra Nova standardized test scores (assessments of Reading or Language Arts, Mathematics, Science, and Social Studies).	Cognitive performance and AP were not affected by the timing of physical education class enrollment. Vigorous PA was positively and significantly related to cognitive performance and AP, whereas these subjects were not associated with moderate PA.
Huang et al[40], 2006	Associations of adiposity with measured and self-reported academic performance in early adolescence.	To examine the associations of adiposity with measured and self-reported academic performance independently of demographics and physical activity among U.S. adolescents.	666/ 11-14 years/ US / Cross sectional	Self-reported type and intensity of PA measured by a modified version of the Previous Day Physical Activity Recall, in 30-minute blocks of time from the moment they awaken to the moment they go to bed.	Self-reported grades (average) in the last year on a 4-point scale and GPA reported by school on a 4-point scale.	Level of MVPA time was negatively related to measured and self-reported grades, independently of adiposity ($p < 0.01$).

Nelson & Gordon-Larsen, [51] 2006	Physical activity and sedentary behavior patterns are associated with selected adolescent health risk behaviors.	To examine relationships between PA and sedentary behavior patterns and an array of risk behaviors, including leading causes of adolescent morbidity/mortality.	11,957/ 13-18 years/ US / Longitudinal	Self- reported daily PA by 7-Day Recall Questionnaire (in categories of housework, hobbies, active play, sports, exercise) for participation in school physical education (days/week) and school-based sports and academic clubs (number/year).	Self-reported and dichotomized into a grade of "A" for Math, Science and English during the most recent grading period.	Independent of age, gender, race/ethnicity and socioeconomic status: -Adolescents with ≥5 weekly bouts of MVPA were more likely to achieve grades of "A" in Math and Science. -The cluster of adolescents who engaged in sports with their parents was more likely to achieve an "A" in Math and English. - The cluster of adolescents who were active in school was more likely to earn high grades.
Sigfúsdóttir *et al.*,[41] 2007	Health behaviour and academic achievement in Icelandic school children.	To identify the relative contribution of body mass index, diet and PA as correlates of AP.	5,810/ 14-15 years/ Iceland/ Cross sectional	Self-reported weekly frequency of PA by 4 questions which account for different levels of PA on a 6-point scale.	Self-reported GPA of Icelandic, Mathematics, English and Danish (alternatively Swedish or Norwegian).	The correlation between PA and GPA was positive ($r = 0.09$) and significant ($P < 0.01$) but only of modest strength. PA was a weak but significant ($P < 0.01$) predictor of AP when controlling for gender, parental education, family structure and absenteeism, but non-significant when depressed mood and self-esteem were included.
Kwak *et al.*,[48] 2009	Associations between physical activity, fitness and academic achievement	To explore the associations between objectively assessed intensity levels of PA and academic achievement and test whether cardiovascular fitness mediates the association between PA and academic achievement.	232/ 15-16 years / Finland / Cross sectional	The average minutes per day spent in light (<3 METs), moderate (3-6 METs) and vigorous (>6 METs) PA measured by accelerometer.	The sum of grades for the 17 subjects (Swedish, English, Biology, Chemistry, Physics, Mathematics, Social Sciences, History, Geography, Religion, Physical Education, Health and five additional subjects of preference) reported by the school.	After controlling for confounding factors, academic achievement was associated with vigorous PA in girls (β =0 .30, P <0.01), which remained after inclusion of fitness ($\beta = 0.23$, P < 0.05).

Fox *et al.*,[42] 2010	Physical activity and sports team participation: associations with academic outcomes in middle school and high school students	To examine the associations between sports team participation, PA, and academic outcomes in middle and high school students.	4,746/ 11-18 years / US / Cross sectional	Self-reported weekly hours of PA by a modified version of the Leisure Time Exercise Questionnaire (LTEQ) and sports team participation (During the past 12 months, on how many sports teams did you play?)	Self- reported GPA of the two grades that were achieved most often by students.	There was a significant linear association between performing more hours of MVPA and a higher GPA for both genders and school groups. The trend between sports team participation and GPA was only significant for high school students. PA and sports team participation were each independently significantly associated with a higher GPA among high school students and high school girls respectively.
Kantomaa *et al.* ,[43] 2010	Physical activity, emotional and behavioral problems, maternal education and self-reported educational performance of adolescents	To examine how physical activity, emotional and behavioral problems and socio-economic position are associated with the academic performance of adolescents.	7,009/ 15-16years/ Finland/ Cross sectional	Self-reported participation (hours per week) in MVPA outside school hours.	Summary score of self-reported grades (Finnish, general subjects, Mathematics and Natural Sciences) on a 4-point scale (from above average=1 to bottom=4)	PA was associated with high overall AP. When results were adjusted for emotional, behavioral and social problems and mother's education, PA was more positively associated with high overall AP among boys than girls.
Kristjánsson *et al.* ,[44] 2010	Health behavior and academic achievement among adolescents: the relative contribution of dietary habits, physical activity, body mass index, and self-esteem	To estimate the relationship between health behaviors, body mass index, and self-esteem and the academic achievement of adolescents	6,346/ 14-15 years/ Iceland/ Cross sectional	Self-reported frequency of physical activity (How often do you participate in sports with a sports club or a team? How often do you physically test yourself so you wind yourself significantly or sweat?), on a 6-point scale.	Self-reported average grades in Mathematics, English, and Danish or, alternatively, Swedish or Norwegian.	PA was significantly associated with higher academic achievement (β=.08, t>1.96), but to a lesser extent indirectly related to achievement (β=.02, t >1.96) through self-esteem.

Rees & Sabia,[52] 2010	Sports participation and academic performance: evidence from the national longitudinal study of adolescent health	To examine the effect of sports participation on several measures of AP.	20,746/ high-school age students/ US/ Longitudinal	Self-reported sports participation during the previous week on a 4-point scale: (i) not at all, (ii) 1 or 2 times, (iii) 3 or 4 times, and (iv) 5 or more times.	Self-reported GPA in Math, Science, History, and English. Three dichotomous variables: (i) difficulty paying attention in class, (ii) difficulty completing their homework on time and (iii) aspirations to go to college.	Math and English GPA and comprehensive GPA (grades in Math, English, Science and History) were positively related to frequency of participation. Sports participation was associated with increases in GPA for girls, but not boys. While OLS estimates consistently showed a higher effect on grades, fixed effects and instrumental variables estimates were much smaller in magnitude or were of the opposite sign.
Ruiz *et al*.,[21] 2010	Physical activity, fitness, weight status, and cognitive performance in adolescents	To examine the association of participation in physical sports activity during leisure time, sedentary behaviors, cardiorespiratory and muscular fitness, and weight status with cognitive performance in Spanish adolescents	1,820/ 13-18.5 years/ Spain / Cross sectional	Self- reported physical sport activity participation during leisure time (Do you practice any type of physical sports activity outside of school time? yes/no)	Cognitive performance (ver bal, numeric, and reasoning abilities and an overall score) was measured by the Spanish version of the SRA Test of Educational Ability.	Participation in physical sports activities during leisure time was associated with better cognitive performance study variables (all P < .001), independent of potential confounders including cardiorespiratory fitness and body mass index.
Travlos,[54] 2010	High intensity physical education classes and cognitive performance in eighth-grade students: an applied study	To analyze the physical fitness, self-concept, atti-tudes toward physical education, and academic achievement of Turkish elementary school children by socioeconomic status.	48/13-15 years/ Greece / Interventional	Intervention task: an interval aerobic run was employed to increase PA during four physical education classes that met at different times during the school day.	A 2-min mathematics task	The intense interval aerobic run significantly affected numeric speed and accuracy of simple addition problems. Students who attended the 1st, 3rd, and 5th hour of the daily classes had significantly higher AP, while the performance of students who attended the 6th-hour physical education class was decreased.

Martínez-Gómez *et al.*,[45] 2011	Active commuting to school and cognitive performance in adolescents: the AVENA study	To examine the associations between active commuting to school and cognitive performance in adolescents.	1,700/ 13-18.5 years/ Spain / Cross sectional	Self- reported mode and duration of transportation to school and participation in extracurricular PA.	Cognitive performance (ver bal, numeric, and reasoning abilities and an overall score) was measured by the Spanish version of the SRA Test of Educational Ability.	Active commuting to school was significantly associated with better cognitive performance in girls but not in boys, independent of potential confounders including participation in extracurricular PA.
Morales *et al.*,[46] 2011	Physical activity, perceptual-motor performance, and academic learning in 9-to-16-years-old school children	1) to evaluate the relationship between perceptual-motor skills and cognitive skills in a group of 9-16 year old males and females, and 2) to compare results in academic and perceptual-motor tests of participants (9-16 years, male and female) that take part in extracurricular PA programs versus those participants that only do PA as part of their physical education curriculum.	487/ 9-16 years/ Spain / Cross sectional	Self- reported extra-curricular amount of PA by a modified version of IPAQ questionnaire. Classifying as participated in extracurricular activities or non-participated in extracurricular activities.	Measures of AP were based on indicators that provide information about the individuals' cognitive aspects. Two subtests from the BADYG battery: the oral skill test and the math skill test.	Subjects participating in extracurricular PA obtain high scores on oral and math skill tests. In the 9-to-12-year-old age group there were significantly better results in both tests. In the 13-to-16-year-old age group there were relationships between PA and AP, but there were no significant differences.

Morales *et al.*,[47] 2011	Relation between physical activity and academic performance in 3rd- year secondary education students	To analyze the relationship between the amount of PA and AP in 3rd-year secondary education students.	284/ a mean age of 14.7 years / Spain / Cross sectional	Self-reported amount of PA by a short version of IPAQ. Results were transformed in METs and categorized into 3 groups: (i) Lower than 1000, (ii) between 1000 & 2500, (iii) more than 2500.	GPA of the 10 subjects provided by every high school.	There was a statistically significant linear correlation between PA and AP with a small magnitude (r=.31).This relationship showed greater AP for the high and moderate activity groups than for the low activity group. There were no differences between the moderate and the high activity groups. The quadratic relationship between PA and AP was not statistically significant.
So,[50] 2012	Association between physical activity and academic performance in Korean adolescent students	To investigate the effects of various types of PA undertaken at various frequencies, on the AP of Korean adolescent students.	75,066/ 13-18 years/ Korea / Cross sectional	Self- reported weekly frequency of vigorous PA, moderate PA and strengthening exercises on a 6-point scale.	Self-reported average AP in the past 12 months on a 5-point scale (from very good performance=1 to very bad performance=5).	Vigorous PA was positively correlated with AP in the case of boys, and moderate PA was positively correlated with AP in both boys and girls. However, strengthening exercises were not positively correlated with AP in boys or girls.
Kim & So,[49] 2012	The relationship between school performance and the number of physical education classes attended by Korean adolescent students	To examine whether the number of physical education classes attended per week is related to school performance in Korean adolescent students.	75,066/ 13-18 years/ Korea / Cross sectional	Self-reported weekly frequency of physical education classes on a 4-point scale, categorized into 2 groups: (1) > 3 physical education classes per week (2) < 3 physical education classes per week.	Self-reported average AP in the past 12 months on a 5-point scale (from very good performance=1 to very bad performance=5).	Students attending <3 physical education classes per week, good school performance increased by 12.5%, average school performance increased by 14.7%, poor school performance increased by 14.6%, and very poor school performance increased by 19.1% as compared to very good school performance, after adjusting for covariate variables such as gender, age, body mass index, parents' education level, family's economic status, vigorous and moderate PA, and muscle strengthening exercises.

PA, physical activity; AP, academic performance; GPA, grade point average; MVPA, moderate to vigorous PA; METs, metabolic equivalents

II

OBJECTIVELY MEASURED PHYSICAL ACTIVITY AND ACADEMIC PERFORMANCE IN YOUTH. THE UP & DOWN STUDY.

Esteban-Cornejo I, Tejero-González CM, Martínez-Gómez D, Cabanas-Sánchez V, Fernández-Santos J, Conde-Caveda J, Sallis JF, Veiga OL.

Acta Paediatrica

Revised version submitted

Objectively measured physical activity and academic performance in children and adolescents. The UP&DOWN Study.

Irene Esteban-Cornejo[1], MSc; Carlos Mª Tejero-González[1], PhD; David Martínez-Gómez[1], PhD; Verónica Cabanas-Sánchez[1], MSc; Jorge R. Fernández-Santos[2], MSc ; Julio Conde - Caveda[2], PhD; James F. Sallis[3], PhD; Oscar L. Veiga[1] , PhD; on behalf of UP & DOWN Study Group*.

[1]Department of Physical Education, Sports and Human Movement, Autonomous University of Madrid, Madrid, Spain.

[2] Department of Physical Education, School of Education, University of Cadiz, Puerto Real, Spain.

[3] Department of Family and Preventive Medicine, University California San Diego, San Diego, CA, USA

SHORT TITLE: Physical activity and academic performance.

Address for correspondence:

Irene Esteban-Cornejo

Department of Physical Education, Sports and Human Movement.

Universidad Autónoma de Madrid

Ctra de Colmenar km 15, 28049 Madrid

Tf: + 34 91 497 21 16 Fax: +34 91 497 84 80

Email: irene.esteban@uam.es

LIST OF ABBREVIATIONS

MVPA, moderate to vigorous physical activity; MPA, moderate physical activity; VPA, vigorous physical activity; GPA, grade point average; CI, confident interval; CPM, count per minutes

***The UP & DOWN Study Group:**

Coordinator: Ascension Marcos. *Principal Investigators*: Ascension Marcos, Oscar L. Veiga, Jose Castro-Piñero, and Fernando Bandrés. *Scientific Coordinators*: David Martinez-Gomez (chair), Jonatan R. Ruiz (co-chair), Ana Carbonell-Baeza, Sonia Gomez-Martinez, and Catalina Santiago. *Spanish National Research Council:* Ascension Marcos, Sonia Gomez-Martinez, Esther Nova, Esperanza L. Diaz, Belén Zapatera, Ana M. Veses, Jorge R. Mujico, and Alina Gheorghe. *Autonomous University of Madrid*: Oscar L. Veiga, H. Ariel Villagra, Juan del-Campo, Carlos Cordente (UPM), Mario Diaz, Carlos M. Tejero, Aitor Acha, Jose M. Moya, Alberto Sanz, David Martinez-Gomez, Veronica Cabanas-Sanchez, Gabriel Rodriguez-Romo (UPM), Rocio Izquierdo, Laura Garcia-Cervantes, and Irene Esteban-Cornejo. *University of Cadiz*: José Castro-Piñero, Jesús Mora-Vicente, José L. González-Montesinos, Julio Conde-Caveda, Francisco B. Ortega (UGR), Jonatan R. Ruiz (UGR), Carmen Padilla Moledo, Ana Carbonell Baeza, Palma Chillón (UGR), Jorge del Rosario Fernández, Ana González Galo, Gonzalo Bellvís Guerra, Álvaro Delgado Alfonso, Fernando Parrilla, Roque Gómez, and Juan Gavala. *Complutense University of Madrid*: Fernando Bandrés, Alejandro Lucia (UEM), Catalina Santiago (UEM), and Felix Gómez-Gallego (UEM).

ABSTRACT

Aim: To examine the association of objectively measured physical activity with academic performance in a relatively large sample of children and adolescents.

Methods: This study was conducted with a total of 1778 youth aged 6-18 years. Physical activity was objectively measured by accelerometry. Academic performance was assessed through grades reported by schools.

Results: Physical activity was inversely associated with all academic performance indicators after adjustment for potential confounders including neonatal variables, fatness and fitness (all $p<0.05$). This association became non-significant among quartiles of physical activity. There were only slight differences in academic performance between the lowest and the second quartile compared to the highest quartile of physical activity with very small effect size ($d< 0.20$).

Conclusions: Objectively measured physical activity may influence academic performance during both childhood and adolescence; however this association was negative but very weak.

Key words: academic performance, accelerometry, adolescents, children, physical activity.

KEY NOTES:

This study provides evidence that objectively measured physical activity may influence academic performance in both children and adolescents, independently of potential confounders, including neonatal variables, fatness and fitness. This association was negative but very weak.

INTRODUCTION

Children and adolescents should participate in at least 60 minutes daily of moderate to vigorous physical activity (MVPA) to achieve substantial health benefits (1). Although physical health benefits are known (2,3), there is an emerging body of evidence of the potential effects of regular physical activity on academic performance (4,5).

The majority of studies investigating associations between physical activity and academic performance in youth relied in self-reported measures of physical activity (7- 15), which have demonstrated lower validity than objective measures, such as accelerometers (6). These studies mainly showed either positive association (8-12) or no association between self-reported physical activity and academic performance in youth (13-15). There are only four studies that objectively assessed physical activity in relation to academic performance (16-19). Two studies found null association between physical activity and academic performance in students aged 10 to 12 years (16,17). A study in a small sample of 15- to16-year-old adolescents found that vigorous physical activity (VPA) was positively associated with academic performance only in girls (18), and another study showed both positive and negative associations between academic indicators and physical activity variables in adolescents (19).

As such, it is difficult to draw a conclusion from previous studies due to their contradictory results. Additionally, such studies were solely focused on adolescents. Adolescence is a period involving important psychological and physiological changes; however, the transitions from early childhood to middle childhood and adolescence imply lifestyle changes which might affect physical activity and academic performance. To the best of our knowledge there is no evidence focused on both children and adolescents.

The present study examined the association of objectively measured physical activity with academic performance in a relatively large sample of children and adolescents aged 6 to 18 years.

METHODS

Sample and study design

The UP&DOWN is a 3-year longitudinal study designed to assess the impact over time of physical activity and sedentary behaviors on health indicators (i.e. physical fitness, metabolic and cardiovascular disease risk factors, inflammation-immunity biomarkers and mental health), as well as to identify the psycho-environmental and genetic determinants of physical activity in a Spanish sample of children and adolescents (20). Children and adolescents were recruited from schools in Cadiz and Madrid, respectively. A total of 2225 youth aged 6 to 18 years participated in the UP&DOWN study. The present analyses included 1778 youth (870 girls; 79% of the original sample) with complete data at baseline on maternal education level, objectively measured physical activity and academic performance. Data collection was undertaken from September 2011 to June 2012.

Previous to participate in the UP&DOWN study, parents and school supervisors were informed by letter about the study and written informed consent was provided. The study protocols were approved by the Ethics Committee of the Hospital Puerta de Hierro (Madrid, Spain) and the Bioethics Committee of the National Research Council (Madrid, Spain).

Physical activity

Objectively measured physical activity was obtained by the ActiGraph accelerometer models GT1M, GT3X and GT3X+ (Actigraph TM, LLC, Pemsacola, FL, US). The GT1M is a small and lightweight uniaxial accelerometer (3.8 x 3.7 x 1.8 cm, 27 g) designed to detect vertical accelerations ranging in magnitude from 0.05 to 2.00 g with a frequency response of 0.25-2.50 Hz. The epoch duration was set at 2-second. The GT3X and GT3X+ are triaxial accelerometers (4.6 x 3.3 x 1.5cm, 19 g) capable of measuring accelerations from -6 to 6g with a frequency response of 0.25 to 2.50 Hz. The epoch duration was set at 30 Hz and their data were subsequently converted into 2-second epochs. Recent studies confirm that there is strong agreement among the three models (21). The ActiGraph accelerometers have been widely calibrated for youth in laboratory and free-living conditions (22).

Each participant wore the accelerometer at the lower back for 7 consecutive days, removing it during sleep and water-based activities. The inclusion criteria were an activity monitor recording of at least 10 hours per day for 3 days (23). The data were downloaded and analyzed using the ActiLife software (v.6.6.2 Actigraph TM, Pensacola, FL, US). Before analyses, data were reintegrated into a 10-second epoch (23). Nonwear time was defined as a period of 60 minutes of zero counts and an allowance for up to 2 consecutive minutes [<100 count per minutes (cpm)] with the up/downstream 30 minutes consecutive of zero counts for detection of artifactual movements (23,24). Physical activity was estimated using cut-points of 2000 and 4000 cpm for moderate physical activity (MPA) and VPA, respectively (25). These cut- points to define the intensity categories are similar to those used in previous studies with European children and adolescents (26). The physical activity variables included in this study were minutes per day at MPA, VPA and MVPA.

Academic performance

Academic performance was assessed through school records at the end of academic year. Four main indicators were used: Mathematics, Language, an average of these two core subjects and grade point average (GPA) score (an average of the scores achieved by students in all subjects). For standardized purposes, individual letter grades were converted to numeric data as follows: A = 5, B = 4, C = 3, D = 2, F = 1.

Covariates

Age, sex, city and maternal education level (below university education and university education) were recorded (27). Neonatal characteristics, such as gestational age at time of delivery (weeks) and birth weight (kg) were reported by parents.

Anthropometric measurements and fitness were assessed with the ALPHA health-related fitness test battery for youth (28). Height was measured to the nearest 1 mm and weight to the nearest 0.05 kg using a standard beam balance with a stadiometer (SECA 701; SECA, Hamburg, Germany). Both measurements were performed twice and averages were recorded. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m^2). Cardiorespiratory fitness was assessed by the 20-m shuttle-run test (28). The score was the number of stages completed. Motor fitness was assessed with the 4 × 10-m shuttle-run test of speed-of-movement, agility and coordination. The test was performed twice and the fastest time was recorded in seconds (28). The individual score of each test (cardiorespiratory fitness and motor fitness) was standardized as follows: Z-standardized value = (value − mean)/SD. A single physical fitness score was calculated as the mean of the two z-standardized scores. Before standardization, the motor fitness score was multiplied by −1 since it is inversely related to physical fitness.Neonatal characteristics, anthropometric measurements and fitness were included because we found that these covariates were associated with academic performance in previous works with the present sample (29,30).

Statistical analysis

The characteristics of participants are presented as means (SD) or percentages. Differences between sexes were tested by one-way analysis of variance and Chi-squared tests for continuous and nominal variables, respectively. Preliminary analyses showed no significant interactions of sex and age with physical activity variables (all $p>0.1$)*;* therefore, all participants were analyzed together. All variables were checked for normality of distribution graphically (Q-Q plots) and with standardized normality test, and appropriate transformations applied when necessary. Specifically, only VPA was square root-transformed before analysis to achieve normality in the residuals

The associations between physical activity variables (MPA, VPA and MVPA) and academic performance were analyzed by linear regression using three separate models: model 1 was controlled for sex, age, city and maternal education; model 2 was additionally controlled for birth weight, gestational age and BMI; and model 3 was further adjusted for physical fitness score. Differences in academic performance were examined by sex- and age-specific quartiles of physical activity at different intensities using analysis of covariance for the three previous models. Cohen's effect size statistics (*d*) as standardized mean differences between quartiles and 95% confidence interval (CI) were also calculated. Cohen's *d* values of 0.2, 0.5 and 0.8 are considered small, medium and large effects, respectively (31).

RESULTS

Table 1 shows the descriptive characteristics of the study sample. The levels of fitness were significantly greater in boys than girls ($p<0.001$). Moreover, boys engaged in higher levels of MPA, VPA and MVPA than girls (all $p<0.001$). Girls had higher scores than boys in Language and GPA ($p<0.001$).

Table 1. Descriptive characteristics of study sample

	All	Boys	Girls	$P_{for\ sex}$
n	1778	908	870	
Physical characteristics				
Age (yr)	10.48±3.37	10.39±3.36	10.56±3.38	0.291
Weight (kg)	42.38±16.12	43.04±17.41	41.70±14.63	0.079
Height (cm)	144.24±18.63	145.11±19.89	143.34±17.18	**0.046**
Body mass index (kg/m^2)	19.57±3.69	19.54±3.76	19.59±3.62	0.763
Fitness (z-score) [a]	0.00±0.93	0.26±1.03	-0.28±0.73	**<0.001**
Maternal education level university (%)	29	32	26	**0.009**
Physical activity				
Moderate PA (min/day)	47.12±15.32	51.62±15.76	42.41±13.31	**<0.001**
Vigorous PA (min/day) [b]	20.97±12.52	25.83±13.26	15.89±9.30	**<0.001**
MVPA (min/day)	68.08±24.18	77.45±24.32	58.30±19.77	**<0.001**
Academic performance				
Math (1-5)	3.33±1.33	3.35±1.32	3.31±1.34	0.513
Language (1-5)	3.36±1.31	3.23±1.35	3.49±1.25	**<0.001**
Math & Language (1-5)	3.34±1.24	3.29±1.26	3.40±1.21	0.056
Grade point average (1-5)	3.56±0.93	3.48±0.96	3.65±0.90	**<0.001**

Values are mean ± SD or percentages. PA, physical activity. MVPA, moderate to vigorous PA [a] z-score computed from cardiorespiratory and motor fitness tests. [b] Square root-transformed values were used in the analysis, but non-transformed values are presented in the table.

Table S2 shows the association of physical activity with academic performance. In model 1, MPA and MVPA were inversely associated with all academic performance indicators (all $p<0.05$). In model 2, these associations remained significant, except for the association of MVPA with GPA score ($p=0.118$). In model 3, after further adjustment for fitness, MPA, VPA and MVPA were inversely associated with all academic performance indicators (all $p<0.05$)

Table S2. Associations of physical activity with academic performance in children and adolescents (*n*=1778).

	Math		Language		Math & Language		Grade point average	
	β	*P*	*β*	*P*	*β*	*P*	*β*	*P*
Model 1								
Moderate PA (min/day)	-0.086	**0.001**	-0.074	**0.003**	-0.085	**0.001**	-0.089	**<0.001**
Vigorous PA (min/day) [a]	-0.007	0.754	-0.016	0.502	-0.016	0.502	0.009	0.723
MVPA (min/day)	-0.059	**0.015**	-0.058	**0.018**	-0.062	**0.010**	-0.052	**0.033**
Model 2								
Moderate PA (min/day)	-0.074	**0.005**	-0.059	**0.029**	-0.071	**0.007**	-0.067	**0.013**
Vigorous PA (min/day) [a]	-0.013	0.617	-0.020	0.431	-0.020	0.431	0.002	0.932
MVPA (min/day)	-0.053	**0.038**	-0.049	0.063	-0.054	**0.034**	-0.041	0.118
Model 3								
Moderate PA (min/day)	-0.109	**<0.001**	-0.082	**0.003**	-0.102	**<0.001**	-0.102	**<0.001**
Vigorous PA (min/day) [a]	-0.079	**0.003**	-0.080	**0.003**	-0.080	**0.003**	-0.063	**0.019**
MVPA (min/day)	-0.109	**<0.001**	-0.087	**0.001**	-0.105	**<0.001**	-0.097	**<0.001**

Values are standardized regression coefficients (*β*).PA, physical activity; MVPA, moderate to vigorous PA. [a] Square root-transformed values were used in the analysis. Model 1: Analyses were adjusted by sex, age (years), city (Cadiz/Madrid), and maternal education (university level/below university level). Model 2: Adjustments for model 1 plus birth weight (kg), gestational age (week), and body mass index (kg/m^2). Model 3: Adjustments for model 2 including fitness (z-score values computed from cardiorespiratory and motor fitness tests).

Table 3 shows the differences in academic performance between quartiles of MPA, VPA and MVPA. In model 1 and 2, there were only significant differences in Mathematics between quartiles of MPA (p<0.05). In model 3, there were slight differences in three academic performance indicators between the lowest and the second quartile compared to the highest quartile of MPA with very small effect size (all d< 0.20). For Language, there were only small differences between the lowest quartile and the highest quartile of MPA (d=0.12; 95% CI,−0.01 to 0.33). Among quartiles of MVPA, there were slight differences in two academic indicators between the lowest and the highest quartile of MVPA with very small effect sizes: for Mathematics d = 0.10 (95% CI,−0.03 to 0.23), and for the average of Mathematics and Language d = 0.09 (95% CI,−0.04 to 0.22).

Table 3. Differences in academic performance according to quartiles of physical activity in children and adolescents (*n*=1778).

	Q_1 Mean±SD	Q_2 Mean±SD	Q_3 Mean±SD	Q_4 Mean±SD	P Model 1	P Model 2	P Model 3
Moderate PA							
Math (1-5)	3.37±1.26[a]	3.44±1.33[b]	3.29±1.35	3.20±1.36	**0.024**	**0.026**	**<0.001**
Language (1-5)	3.42±1.25 [a]	3.43±1.29	3.34±1.33	3.26±1.35	0.240	0.0269	**0.047**
Math & Language (1-5)	3.40±1.17[a]	3.43±1.23[b]	3.31±1.25	3.23±1.27	0.060	0.069	**0.003**
Grade point average (1-5)	3.61±0.88 [a]	3.65±0.90 [b]	3.53±0.96	3.46±0.99	0.068	0.075	**0.003**
Vigorous PA							
Math (1-5)	3.31±1.34[a]	3.32±1.26	3.36±1.35	3.32±1.36	0.991	0.989	0.143
Language (1-5)	3.36±1.31	3.37±1.26	3.38±1.30	3.32±1.36	0.939	0.864	0.164
Math & Language (1-5)	3.34±1.25[a]	3.35±1.18	3.37±1.24	3.32±1.28	0.993	0.956	0.109
Grade point average (1-5)	3.53±0.93	3.56±0.89	3.58±0.93	3.58±0.97	0.861	0.990	0.270
Moderate to vigorous PA							
Math (1-5)	3.37±1.28[a]	3.37±1.31	3.33±1.35	3.24±1.36	0.421	0.318	**0.004**
Language (1-5)	3.40±1.25	3.39±1.30	3.33±1.33	3.31±1.34	0.605	0.508	0.095
Math & Language (1-5)	3.39±1.19[a]	3.38±1.22	3.33±1.26	3.28±1.27	0.494	0.380	**0.013**
Grade point average (1-5)	3.58±0.88	3.59±0.94	3.56±0.94	3.52±0.97	0.860	0.741	0.052

Values are standardized regression coefficients (β). PA, physical activity. Model 1: Analyses were adjusted by sex, age (years), city (Cadiz/Madrid) and maternal education (university level/below university level). Model 2: Adjustments for model 1 plus birth weight (kg), gestational age (week) and body mass index (kg/m^2). Model 3: Adjustments for model 2 including fitness (z-score values computed from cardiorespiratory and motor fitness tests). [a] Significantly differences between Q_1 and Q_4 for model 3. [b] Significantly differences between Q_2 and Q_4 for model 3.

DISCUSSION

We examined the associations of objectively measured physical activity with academic performance in children and adolescents. The main finding of the present study was that physical activity was negatively associated with academic performance, independent of potential confounders, including neonatal variables, fatness and fitness. However, this association was negative but very weak.

These results may be indicative of more physically active youth spending less time on studying. To confirm this hypothesis, in *post hoc* analysis with a subsample (n=1217; 49%girls) of the present study with information on time spent studying, we found a weak relationship between time spent studying and physical activity ($r = -0.178, -0.145$ and -0.184 for MPA, VPA, MVPA respectively) However, when including the time spent studying as a covariate in all analyses, the results were virtually the same and there were no evidence of a moderating effect of time spent studying (i.e. p for physical activity variables*time spent studying interactions >0.1) on the association between physical activity and academic performance. Although the present results concur with a previous study, which used self-reported measurements of physical activity (7), there is strong evidence using self-reported physical activity measurements that has mainly showed a positive association with academic performance (8-12). Few studies found no association between academic performance and self-reported physical activity in youth (13-15).

The lack of agreement between studies using self-reported and objective measures of physical activity in relation to academic performance might be due to the inherent characteristics of physical activity measures. Self-reported physical activity assesses specific domains of physical activity (e.g. extracurricular physical activity, physical education, active commuting, athletic participation), whereas accelerometry covers the complete range of physical activity in which youth are involved. Thus, the association between physical activity and academic performance might depend on which specific component of total physical activity is measured. For example, studies using self-reported physical activity measures providing a portion of youth's daily physical activity, such as physical education or athletic participation, showed a positive association with academic performance (10,11). Additionally, studies using self-reported physical activity questionnaires to estimate weekly physical activity also found a positive association with academic performance (8,9). This reason could partially explain why studies using self-reported physical activity showed mainly positive associations with academic performance while findings with objective measures of physical activity are controversial. However, further longitudinal research taking into account repeated measures of both outcomes (academic performance indicators) and exposures (objectively measured physical activity) is necessary to clarify the aforementioned association.

Few studies have investigated the associations between objectively measured physical activity and academic performance (16-19). It is important to investigate this association because physical activity provided plasticity and flexibility to the brain, which in turn may have a positive influence on academic performance (32). Two recent studies in students aged 10-12 years found no association between objectively measured MVPA and academic performance (16,17). However, Kwak et al. in a sample of 233 adolescents aged 15-16 years showed that VPA was the only intensity level positively associated with academic performance, but solely in girls, which remained after controlling for fitness and maternal education (18). A longitudinal study found positive and negative association between MVPA and academic performance depending on whether total physical activity (i.e. cpm) was taken into account or not as cofounder, respectively (19). In the present study, we also found a negative relationship between the time spent at different physical activity intensities and academic performance when total physical activity was not taken into account; however when we included total physical activity, it yielded no significant associations. The role which total physical activity plays in this association is difficult to interpret because includes all physical activity intensities. In this sense, adding in the same analyses both total physical activity and the time spent at any physical activity may be over-adjusting the association.

The inconsistent findings in studies using accelerometers may be explained not only through the variations in samples and methods (e.g. the age range, accelerometer procedures), but also multiple other factors may contribute to such contradictory evidence. First, academic performance was differently assessed through grades (16,18) and standardized tests (17,19). Our academic indicators were also grades, however grades were related not only to academic skills, but also to teacher perception, the quality and quantity of academic teaching, family background and environment, and even cultural factors. Therefore, the academic indicator used (e.g. grades, standardized tests, cognitive skills tests) may be important to avoid bias (33).

Second, several confounding factors included in our study were not always taken into account in the previous studies, making comparisons difficult. For example, birth weight and gestational age, variables broadly related to academic and cognitive performance (34), were only included in one study (19). Fitness was incorporated as a covariate in only one other study (18). According to Etnier et al, fitness may mediate the relationship between physical activity and academic performance (35). We found that fitness was related to physical activity and to academic performance, therefore, fitness might indeed be mediated such association in our results. However, our findings and those from Kwak et al. showed there was no mediated effect between physical activity an academic performance through fitness (18). Lastly, it is possible that the volume of daily physical activity at different intensities is not a good indicator of the quality of physical activity related to academic performance. Future studies should investigate the association between objectively measured physical activity in specific periods (e.g. recess, physical education, active breaks) in relation to academic performance.

The present study has some limitations. The cross-sectional design, which precludes the possibility to draw conclusions regarding the causality of the observed associations. The fact that it was undertaken a convenience sample, which limits its generalizability across the population. Grades are socially valid measures of academic performance, but they have potential limitations of bias, so studies are recommended using standardized tests and measures of brain function. Strengths of the present study include its relatively large sample of children and adolescents, the use of accelerometers to assess physical activity and the objectively assessment of fitness.

In conclusion, we observed that objectively measured physical activity may influence academic performance in both children and adolescents; however, this association was negative but very weak. Longitudinal and intervention studies are necessary to further understand changes over time in physical activity and academic performance during both childhood and adolescence.

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III

MATERNAL PHYSICAL ACTIVITY BEFORE AND DURING THE PRENATAL PERIOD AND THE OFFSPRING'S ACADEMIC PERFORMANCE IN YOUTH. THE UP&DOWN STUDY

Esteban-Cornejo I, Martínez-Gómez D, Tejero-González CM, Izquierdo-Gómez R, Carbonell-Baeza A, Castro-Piñero, Sallis JF, Veiga OL

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Maternal physical activity before and during the prenatal period and the offspring's academic performance in youth. The UP&DOWN Study.

Irene Esteban-Cornejo[a], MSc; David Martínez-Gómez[a], PhD; Carlos Mª Tejero-González[a], PhD; Rocio Izquierdo-Gómez[a], MSc; Ana Carbonell-Baeza[b], PhD; José Castro-Piñero[b], PhD; James F. Sallis[c], PhD; Oscar L. Veiga[a] , PhD; on behalf of UP & DOWN Study Group*.

[a]Department of Physical Education, Sports and Human Movement, Autonomous University of Madrid, Madrid, Spain.

[b] Department of Physical Education, School of Education, University of Cadiz, Puerto Real, Spain.

[c] Department of Family and Preventive Medicine, University California San Diego, San Diego, CA, USA

Abbreviate title: Maternal physical activity during pregnancy and youth's academic performance.

Address for correspondence:

Irene Esteban-Cornejo

Department of Physical Education, Sports and Human Movement.

Universidad Autónoma de Madrid

Ctra de Colmenar km 15, 28049 Madrid

Tf: + 34 91 497 21 16 Fax: +34 91 497 84 80

Email: irene.esteban@uam.es

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ABSTRACT

Objective: To examine the association of maternal physical activity before and during pregnancy with academic performance in youth.

Methods: This cross-sectional study was conducted with a total of 1868 youth aged 6-18 years and their mothers, in two cities (Cadiz and Madrid) in Spain. Maternal physical activity was self-reported. Academic performance was assessed through school records basing on four indicators: Math, Language, an average of these two core subjects and grade point average score.

Results: Boys whose mothers practiced physical activity before or during pregnancy had significantly higher scores in academic performance indicators independently of physical activity, fitness, current BMI, and birth weight than those whose mothers did not practice physical activity before or during pregnancy (all $p < 0.05$). In addition, boys whose mothers were in the "pre-active to active" group had higher scores in all academic indicators (ranging from +0.358 to +0.543) than boys whose mothers were in the "pre-inactive to inactive" group. Boys whose mothers were in the "pre-active to active" group had higher scores in Language (score +0.546; 95% CI, 0.150-0.940), average of Math and Language (score +0.468; 95% CI, 0.100-0.836) and GPA (score +0.368; 95% CI, 0.092-0.644) than boys whose mothers were in the "pre-inactive to active" group.

Conclusions: Maternal physical activity before and during pregnancy may positively influence youth's academic performance. Continuing maternal physical activity practice during pregnancy may have greater benefits for youth's academic performance.

Keywords: academic performance, maternal physical activity, pregnancy, youth.

Abbreviations:

ANCOVA Analysis of covariance

BDNF mRNA Brain-derived neurotrophic factor messenger ribonucleic acid

BMI Body mass index

GPA Grade point average

IGFBP-1 Insulinlike growth factor-binding protein 1

INTRODUCTION

There is increasing evidence that prenatal environment influences fetal development and may have implications for the offspring's health later in life (Gluckman et al., 2008; Norris et al., 2012; van Deutekom et al., 2013). Medical and scientific groups such as the American College of Obstetrics and Gynecology, the US Department of Health and Human Services and the American College of Sports Medicine recommend that pregnant women engage in regular physical activity (Artal and O'Toole, 2003; US Dept of Health and Human Services, 2008; ACSM, 2010). A growing body of evidence suggests that maternal prenatal physical activity has both short- (i.e. decreased resting fetal heart rate, increased amniotic fluid levels, increased endothelium-dependent vasodilation) and longer-term benefits (i.e. lower birth weights, increased gestational ages) on the offspring (Mattran et al., 2011; Hopkins et al., 2011; Ramirez-Velez et al., 2011; May et al., 2012). Little is known, however, about the effects of maternal physical activity during this period on the offspring's cognitive development (LeMoyen et al., 2012).

Only a few studies have examined the association between maternal physical activity during pregnancy and the offspring’s cognitive functioning. Such studies used small sample sizes (n<105) and focused on the first years of life (<6 years); thereby long-term effects cannot be elucidated (Clapp, 1996; Clapp et al., 1998;Clapp et al., 1999). Additionally, these studies did not take into account the independent effect of pre-pregnancy physical activity. Interestingly, maternal physical activity before pregnancy might facilitate physical activity during pregnancy and prepare mothers for a healthy pregnancy (Owe et al., 2009). In addition, as women usually do not realize they are pregnant for the first few weeks, when essential fetal processes have already started, physical activity begun during pregnancy may miss the periconceptional period (Chapin et al., 2004). Therefore, practicing physical activity before pregnancy may be at least as important as during pregnancy. To the best of our knowledge, there is no study investigating the association between prenatal physical activity of women and youth academic performance. The present study examined the association of maternal physical activity before and during pregnancy with academic performance in youth aged 6-18 years.

MATERIALS AND METHODS

Participants

This research was based on data from the UP&DOWN study. In brief, the UP&DOWN study is a 3-year longitudinal study designed to assesses the impact over time of physical activity and sedentary behaviors on health indicators in a Spanish sample of children and adolescents. Data were collected from September 2011 to June 2012. Children and adolescents were recruited from schools in Cadiz and Madrid, respectively. A total of 1868 youth (921 girls) aged 6-18 years with complete data at baseline on mother's physical activity and child's academic performance were included in the present report.

Parents and school supervisors were informed by letter about the nature and purpose of the study, and written informed consent was provided. The study protocols were approved by the Ethics Committee of the Hospital Puerta de Hierro (Madrid, Spain) and the Bioethics Committee of the National Research Council (Madrid, Spain).

Maternal physical activity before and during pregnancy

Mothers answered the following questions: "Do you practice physical activity before pregnancy?, and "Do you practice physical activity during pregnancy?. The possible answers were yes or no.

Youth academic performance

Academic performance was assessed through school records at the end of the academic year. Grade point average (GPA) score was standardized by calculating a single average for the examinable subjects in each grade. Academic performance was based on four indicators: Math, Language, an average of these two core subjects and GPA score. For analytic purposes, individual letter grades were converted to numeric data as follows: A = 5, B = 4, C = 3, D = 2, and F = 1.

Covariates

Participants' age, sex, city (Cadiz/Madrid) and maternal education level (below university education and university education) were recorded (Klein-Platat et al., 2003). Gestational age at time of delivery (weeks) and birth weight (kg) were reported by parents.

Anthropometric measurements and fitness in participants were assessed followed the ALPHA health-related fitness test battery for youth (Ruiz et al., 2011). Height was measured to the nearest 1 mm and weight to the nearest 0.05 kg using a standard beam balance with a stadiometer (SECA 701; SECA, Hamburg, Germany). Both measurements were performed twice, and averages were recorded. Body mass index (BMI) was calculated as kg/m^2. Cardiorespiratory fitness was assessed by the 20-m shuttle-run test and motor fitness was assessed with the 4 × 10-m shuttle-run test of speed-of-movement, agility and coordination (Van Deutekom et al., 2013).Cardiorespiratory fitness and motor fitness were only included because we found that muscular fitness was not associated with academic performance in a previous study with the present sample (data no published). A single physical fitness score was calculated as the mean of the two z-standardized scores. Because the motor fitness score is inversely related to physical fitness, it was multiplied by −1.

Youth's physical activity was measured by accelerometry (Cain et al., 2013). The physical activity variable included in this study was counts per minute was included as a measure of total physical activity.

Statistical analysis

The characteristics of participants and outcomes are presented as means (SD) or percentages. Differences between sexes were determined by one-way analysis of variance and Chi-squared tests for continuous and nominal variables, respectively. Since significant interactions were found between sex and maternal physical activity in relation to outcomes, all analyses were performed separately for boys and girls.

The association of maternal physical activity before pregnancy (yes/no) with youth's academic performance was analyzed by one-way analysis of covariance (ANCOVA) with Bonferroni adjustment using three separate models: model 1 was controlled for age, city and maternal education; model 2 was additionally controlled for birth weight and gestational age; and model 3 was further adjusted for the current levels of body mass index, physical activity and physical fitness. We also conducted ANCOVA to examine the association of maternal physical activity during pregnancy (yes/no) with youth's academic performance, using the three previous models.

The association of changes in maternal physical activity practice from before (yes/no) to during (yes/no) pregnancy with youth's academic performance was analyzed by ANCOVA, using the same previous models. Youth were categorized into 4 groups according to the physical activity practices of their mothers from before to during pregnancy: “pre-active to active”, “pre-active to inactive”, “pre-inactive to active” and “pre-inactive to inactive”. Analyses were performed with the IBM SPSS Statistics 18.0 for Windows and the level of significance was set to 0.05.

RESULTS

Table 1 shows the descriptive characteristics of the study sample. **Table 2** shows the association of maternal physical activity before pregnancy with youth's academic performance. Across the three models, boys whose mothers practiced physical activity before pregnancy had significantly higher scores in all academic performance indicators than those whose mothers did not practice physical activity before pregnancy (all $p \leq 0.002$).

Table 1. Descriptive characteristics of study sample

	All	Boys	Girls	$P_{for\ sex}$
n	1868	947	921	
Physical characteristics				
Age (yr)	10.18±3.31	10.10±3.30	10.26±3.31	0.288
Weight (kg)	41.21±15.72	41.77±16.84	40.62±14.46	0.113
Height (cm)	142.66±18.23	143.40±19.42	141.90±16.90	0.075
Body mass index (kg/m^2)	19.45±3.68	19.42±3.70	19.47±3.66	0.795
Birth weight (kg)	3.24±0.55	3.30±0.56	3.17±0.54	**<0.001**
Gestational age (wk)	38.79±2.49	38.70±2.39	38.70±2.6	0.966
Maternal education level university (%)	29	32	25	**0.002**
Fitness (z-score) [a]	0.00±0.93	0.25±1.01	-0.26±0.75	**<0.001**
Total PA (cpm)	510.66±141.22	562.37±139.19	457.50±122.43	**<0.001**
Maternal PA				
Active mothers before pregnancy (%)	45	45	45	0.878
Active mothers during pregnancy (%)	41	42	40	0.274
Changes in maternal PA (pre→ during pregnancy)				
Inactive →inactive (%)	44	43	45	0.627
Inactive →active (%)	11	11	11	0.598
Active →inactive (%)	15	14	16	0.403
Active →active (%)	30	31	29	0.416
Academic performance				
Math (1-5)	3.35±1.32	3.37±1.31	3.32±1.34	0.401
Language (1-5)	3.37±1.30	3.23±1.34	3.51±1.25	**<0.001**
Math & Language (1-5)	3.36±1.23	3.30±1.25	3.42±1.21	**0.046**
Grade point average (1-5)	3.58±0.93	3.50±0.94	3.65±0.91	**<0.001**

Values are mean ± SD or percentages. [a] z-score computed from the 20-m shuttle-run test and the 4 × 10-m shuttle-run test. cpm, count per minute; PA, physical activity.

Table 2. Differences in youth academic performance between youth whose mothers practiced physical activity before pregnancy and youth whose mothers did not practice physical activity before pregnancy.

Academic performance	Yes Mean±SD	No Mean±SD	Yes *vs.* No Mean difference (95% CI)	$P_{\text{Model 1}}$	$P_{\text{Model 2}}$	$P_{\text{Model 3}}$
Boys (n= 947)	428	519				
Math (1-5)	3.58±1.20	3.20±1.36	0.386 (0.222, 0.549)	**0.001**	**0.001**	**0.002**
Language (1-5)	3.49±1.26	3.02±1.37	0.472 (0.304, 0.640)	**<0.001**	**<0.001**	**<0.001**
Math & Language (1-5)	3.53±1.17	3.11±1.29	0.429 (0.272, 0.586)	**<0.001**	**<0.001**	**<0.001**
Grade point average (1-5)	3.68±0.87	3.35±0.97	0.331 (0.214, 0.449)	**<0.001**	**<0.001**	**<0.001**
Girls (n=921)	413	508				
Math (1-5)	3.35±1.33	3.30±1.34	0.045 (-0.129, 0.219)	0.661	0.660	0.226
Language (1-5)	3.59±1.23	3.45±1.26	0.136 (-0.026, 0.298)	0.353	0.356	0.774
Math & Language (1-5)	3.47±1.19	3.38±1.22	0.090 (-0.067, 0.247)	0.802	0.805	0.608
Grade point average (1-5)	3.70±0.91	3.61±0.90	0.089 (-0.028, 0.207)	0.534	0.537	0.850

Model 1: Analyses were adjusted by age (years), city (Cadiz/Madrid) and maternal education (university level/below university level). Model 2: Adjustments for model 1 plus birth weight (kg) and gestational age(wk). Model 3: Adjustments for model 2 plus physical activity (cpm), body mass index (kg/m^2) and fitness (z-score).

Table 3 presents the association of maternal physical activity during pregnancy with youth's academic performance. Among boys, those whose mothers practiced physical activity during pregnancy had significantly higher scores in three of the four academic indicators than those whose mothers were not active, across the three models (all $p < 0.05$). For Math score, the association was attenuated in model 2 and 3 ($p < 0.10$).

Table 3. Differences in youth academic performance between youth whose mothers practiced physical activity during pregnancy and youth whose mother did not practice physical activity during pregnancy.

Academic performance	Yes Mean±SD	No Mean±SD	Yes *vs.* No Mean difference (95% CI)	$P_{\text{Model1 l}}$	$P_{\text{Model 2}}$	$P_{\text{Model 3}}$
Boys (n= 947)	402	545				
Math (1-5)	3.51±1.26	3.27±1.33	0.234 (0.066, 0.402)	**0.046**	*0.051*	*0.097*
Language (1-5)	3.42±1.32	3.10±1.35	0.319 (0.147, 0.491)	**0.003**	**0.004**	**0.007**
Math & Language (1-5)	3.46±1.23	3.19±1.26	0.276 (0.115, 0.437)	**0.008**	**0.010**	**0.020**
Grade point average (1-5)	3.61±0.92	3.42±0.92	0.194 (0.074, 0.315)	**0.015**	**0.018**	**0.039**
Girls (n=921)	368	553				
Math (1-5)	3.40±1.30	3.27±1.36	0.125 (-0.051, 0.302)	0.960	0.938	0.689
Language (1-5)	3.59±1.21	3.46±1.27	0.122 (-0.042, 0.287)	0.704	0.701	0.982
Math & Language (1-5)	3.49±1.18	3.37±1.23	0.124 (-0.036, 0.283)	0.820	0.806	0.817
Grade point average (1-5)	3.73±0.88	3.60±0.92	0.123 (0.004, 0.243)	0.374	0.369	0.669

Model 1: Analyses were adjusted by age (years), city (Cadiz/Madrid) and maternal education (university level/below university level). Model 2: Adjustments for model 1 plus birth weight (kg) and gestational age (wk). Model 3: Adjustments for model 2 plus physical activity (cpm), body mass index (kg/m^2) and fitness (z-score).

Table 4 shows the association of maternal physical activity changes from before to during pregnancy with youth academic performance. Among boys, significant differences in all academic performance variables were found across the groups ($p < 0.05$). Boys whose mothers were in the “pre-active to active” group had higher scores in Math (score +0.420; 95% CI, 0.160-0.680), Language (score +0.543; 95% CI, 0.280-0.810) average of Math and Language (score +0.481; 95% CI, 0.232-0.731) and GPA (score +0.358; 95% CI, 0.171-0.546) than boys whose mothers were in the “pre-inactive to inactive” group. Boys whose mothers were in the “pre-active to active” group had higher scores in Language (score +0.546; 95% CI, 0.150-0.940), average of Math and Language (score +0.468; 95% CI, 0.100-0.836) and GPA (score +0.368; 95% CI, 0.092-0.644) than boys whose mothers were in the "pre-inactive to active" group.

Table 4. Differences in academic performance between youth whose mothers changed physical activity practice from pre-pregnancy to pregnancy.

Academic performance	Pre-active→active Mean±SD	Pre-active→inactive Mean±SD	Pre-inactive→active Mean±SD	Pre-inactive→inactive Mean±SD	P Model 1	P Model 2	P Model 3
Boys (n= 947)	294	134	108	411			
Math (1-5)	3.61±1.23[a]	3.52±1.16	3.22±1.28	3.19±1.38	**0.013**	**0.012**	**0.021**
Language (1-5)	3.56±1.27[a,b]	3.34±1.23	3.02±1.36	3.02±1.38	**<0.001**	**<0.001**	**<0.001**
Math & Language (1-5)	3.59±1.20 [a,b]	3.43±1.10	3.12±1.25	3.11±1.30	**0.001**	**0.001**	**0.001**
Grade point average (1-5)	3.71±0.89 [a,b]	3.72±0.83	3.34±0.93	3.35±0.98	**0.001**	**<0.001**	**0.001**
Girls (n=921)	270	143	98	410			
Math (1-5)	3.37±1.30	3.30±1.36	3.47±1.28	3.26±1.36	0.901	0.897	0.548
Language (1-5)	3.57±1.24	3.62±1.23	3.63±1.16	3.41±1.28	0.423	0.420	0.427
Math & Language (1-5)	3.47±1.19	3.46±1.20	3.55±1.15	3.34±1.23	0.763	0.760	0.580
Grade point average (1-5)	3.72±0.90	3.67±0.93	3.74±0.83	3.58±0.92	0.723	0.719	0.743

Model 1: Analyses were adjusted by age (years), city (Cadiz/Madrid) and maternal education (university level/below university level). Model 2: Adjustments for model 1 plus maternal birth weight (kg) and gestational age (wk). Model 3: Adjustments for model 2 plus physical activity (cpm), body mass index (kg/m^2) and fitness (z-score). [a] Significantly differences between “pre-active→active” and “pre-inactive→inactive” categories across the three models. [b] Significantly differences between “pre-active→active” and “pre-inactive→active” categories across the tree models

DISCUSSION

A main finding of the present study was that maternal physical activity before and during pregnancy was related to youth's academic performance in boys, but not in girls. In addition, boys whose mothers were active before and during pregnancy had higher academic performance than those whose mothers continued being inactive or became active. Importantly, these findings were independent of potential confounders, specifically physical activity, fitness, current BMI, and birth weight, which might modify the aforementioned associations due to their relationship with both outcomes and exposures (Van Deutekon et al., 2013; Touwslager et al., 2013). These novel results expand the previous evidence on the benefits of maternal prenatal physical activity on the offspring's health, indicating that an active lifestyle before and during the prenatal period may have a beneficial influence on youth academic performance in boys.

One of the novel aspects in this study was to take into account the independent effect of maternal physical activity before pregnancy on youth's academic performance. We found that boys whose mothers were active before pregnancy had higher scores in all academic indicators than those whose mothers were not active before pregnancy. These encouraging findings may have several explanations. First, women are unaware they are pregnant for the first few weeks, when essential fetal processes have already started. Organogenesis (i.e. the formation and differentiation of organs during embryonic development) extends from the second to the eighth week of gestation. This period is extremely vulnerable, so environmental factors may produce particularly strong influences for embryonic growth, resulting in positive or negative health consequences later in life (Chapin et al., 2004; Mook-Kanamori et al., 2010). Maternal stress early in pregnancy may influence hippocampal dependent learning and memory (Muller and Bale, 2007) as well as increase the risk of schizophrenia in the offspring males (Khashan et al., 2008).

Regular physical activity practice may provide substantial health benefits for women before pregnancy and reduce the risk for an adverse pregnancy (US Dept of Health and Human Services, 2008), for example, preventing maternal overweight, preeclampsia or gestational diabetes (Sorensen et al., 2003; Tobias et al., 2011). Thus, being physically active before pregnancy might counteract, to some extent, such consequences and generate beneficial eventual effects on youth academic performance. A woman's lifestyle before pregnancy is the strongest predictor of her lifestyle during pregnancy (Owe et al., 2009). For example, in the present study, 74% of women who were physically active or inactive before pregnancy maintained their lifestyle during pregnancy. Consequently, women who practice physical activity before pregnancy may be more likely to continue being active during pregnancy, contributing to a greater benefit for youth academic performance later in life.

The present study examined the effect of maternal physical activity during pregnancy on youth's academic performance during childhood and adolescence. Other studies investigated the association between maternal physical activity during pregnancy and the offspring's cognitive functioning in the first years of life. Five days after their birth, the offspring of the mothers who practiced physical activity during pregnancy had higher scores in the orientation and state regulation subscales of the Brazelton Neonatal Behavioral Assessment Scales (Clapp et al., 1999). Another study found that at the age of 1 year there were not differences in mental ability between the offspring whose mothers were active during pregnancy with those whose mothers were not active (Clapp et al., 1998). However, in a separate study, the 5-year-old children of the active mothers group performed better on tests of general intelligence and oral language (Clapp, 1994). Thus, the aforementioned findings seems to be inconsistent throughout the first years of life, and the long-term effects of maternal physical activity during pregnancy on the offspring's cognitive functioning has been inadequately studied. In the present study, boys aged 6 to 18 years whose mothers were active during pregnancy had higher scores in all academic indicators.

Recent evidence in animals supports that maternal physical activity during pregnancy may be beneficial for fetal brain development (Parnpiansil, et al., 2003; Kim et al., 2007; Robinson and Bucci, 2014). Experimental studies in rats showed that physical activity during gestation in pregnant mothers can increase hippocampal BDNF mRNA (Brain-derived neurotrophic factor messenger ribonucleic acid) expression in postnatal pups (Parnpiansil, et al., 2003) and can improve objective recognition memory in adult male offspring (Robinson and Bucci, 2014). It has been previously shown that some maternally derived growth factors (e.g. BDNF) cross the placenta and are active in the fetus (Gilmore et al., 2003). Importantly, BDNF is implicated in brain plasticity, which in turn, may enhance cognitive function (Cotman and Engesser-Cesa, 2002). Thus, the offspring's cognitive and academic performance might be enhanced.

Another interesting finding was that boys whose mothers maintained the physical activity practice during pregnancy scored higher in all academic indicators than those whose mothers continued being inactive or became active. It seems that being physically active just during the pregnancy period could be insufficient to lead to beneficial effects in the offspring's academic performance. Pregnancy lasts 9 months, a short period in which the effects of maternal physical activity on fetus might not have a benefit if the organism was not previously prepared. Regular physical activity enhances important aspects of the maternal physiologic adaptations to pregnancy in ways that are also fetoprotective (Clapp, 1994). However, although we examined maternal physical activity before and during pregnancy separately, it is difficult to determine the independent biological relevance of the two exposure periods. As mentioned, pre-pregnancy physical activity is one of the strongest correlates of physical activity during pregnancy (Owe et al., 2000). In addition, the physical activity recommendation for the general population is similar to that for pregnant women (US Dept of Health and Human Services, 2008). Thus, it is not clear whether physical activity before pregnancy or during pregnancy contributes to the offspring's academic performance, or whether both are required.

The reasons explaining why maternal physical activity before and during the prenatal period might improve academic performance only in the offspring boys cannot be elucidated, yet some candidate mechanisms should be explored. Maternal stressors may impact brain development, especially the hippocampus and hypothalamus, and cognitive abilities in the offspring in a sex-dependent manner (Charil et al., 2010; Bale, 2011). For example, the effect of maternal stress on placental gene expression in mice were found only in the male offspring; male placentas exhibited increases in the expression of several genes important in growth and development such as insulinlike growth factor-binding protein 1 (IGFBP-1) (Mueller and Bale, 2008). An elevation in placental IGFBP-1 could potentially decrease the available growth factors during critical developmental periods, and plays a role in fetal programming and brain development, which were specific to males (Myatt, 2006). In humans, the influence of maternal depression during pregnancy on offspring postnatal anxiety development was detected only in boys (Gerardin et al., 2011). The majority of evidence was focused on negative stressors; however, the offspring outcomes varied depending upon the stressor involved (Brunton and Russell, 2010). As such, physical activity might be a positive stressor for cognitive functioning, as it augments brain plasticity by facilitating adaptive and protective processes through the mediation of BDNF and insulin-like growth factor-1 (Cotman and Berchtold, 2002; Dishman et al., 2006).

The present study had several limitations. The fact that it was undertaken in a convenience sample limits its generalizability. The use of simple, self-reported measures of maternal physical activity must be acknowledged, so present findings must be interpreted with caution. Strengths of the study included the relatively large and heterogeneous sample of children and adolescents, the objective assessment of physical activity and fitness, and the use of school records to assess academic performance.

In conclusion, the results indicated that maternal physical activity before and during pregnancy was positively associated with youth academic performance in boys. Thus, promoting physical activity among women of reproductive age may improve youth academic performance later in life. Further longitudinal studies and clinical trials may help to confirm the sex- and time-specific effects of prenatal maternal physical activity on youth's academic performance.

***The UP & DOWN Study Group:**

Coordinator: Ascension Marcos. *Principal Investigators*: Ascension Marcos, Oscar L. Veiga, Jose Castro-Piñero, and Fernando Bandrés. *Scientific Coordinators*: David Martinez-Gomez (chair), Jonatan R. Ruiz (co-chair), Ana Carbonell-Baeza, Sonia Gomez-Martinez, and Catalina Santiago. *Spanish National Research Council:* Ascension Marcos, Sonia Gomez-Martinez, Esther Nova, Esperanza L. Diaz, Belén Zapatera, Ana M. Veses, Jorge R. Mujico, and Alina Gheorghe. *Autonomous University of Madrid*: Oscar L. Veiga, H. Ariel Villagra, Juan del-Campo, Carlos Cordente (UPM), Mario Diaz, Carlos M. Tejero, Aitor Acha, Jose M. Moya, Alberto Sanz, David Martinez-Gomez, Veronica Cabanas-Sanchez, Gabriel Rodriguez-Romo (UPM), Rocio Izquierdo, Laura Garcia-Cervantes, and Irene Esteban-Cornejo. *University of Cadiz*: José Castro-Piñero, Jesús Mora-Vicente, José L. González-Montesinos, Julio Conde-Caveda, Francisco B. Ortega (UGR), Jonatan R. Ruiz (UGR), Carmen Padilla Moledo, Ana Carbonell Baeza, Palma Chillón (UGR), Jorge del Rosario Fernández, Ana González Galo, Gonzalo Bellvís Guerra, Álvaro Delgado Alfonso, Fernando Parrilla, Roque Gómez, and Juan Gavala. *Complutense University of Madrid*: Fernando Bandrés, Alejandro Lucia (UEM), Catalina Santiago (UEM), and Felix Gómez-Gallego (UEM).

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IV

INDEPENDENT AND COMBINED INFLUENCE OF THE COMPONENTS OF PHYSICAL FITNESS ON ACADEMIC PERFORMANCE IN YOUTH. THE UP & DOWN STUDY.

Esteban-Cornejo I, Tejero-González CM, Martínez-Gómez D, Del-Campo J, González-Galo A, Padilla-Moledo C, Sallis JF, Veiga OL.

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Independent and Combined Influence of the Components of Physical Fitness on Academic Performance in Youth

Irene Esteban-Cornejo, MSc[1], Carlos Ma. Tejero-González, PhD[1], David Martínez-Gómez, PhD[1], Juan del-Campo, PhD[1], Ana González-Galo, MSc[2], Carmen Padilla-Moledo, PhD[2], James F. Sallis, PhD[3], and Oscar L. Veiga, PhD[1], on behalf of the UP & DOWN Study Group*

Objective To examine the independent and combined associations of the components of physical fitness with academic performance among youths.

Study design This cross-sectional study included a total of 2038 youths (989 girls) aged 6-18 years. Cardiorespiratory capacity was measured using the 20-m shuttle run test. Motor ability was assessed with the 4×10-m shuttle run test of speed of movement, agility, and coordination. A muscular strength *z*-score was computed based on handgrip strength and standing long jump distance. Academic performance was assessed through school records using 4 indicators: Mathematics, Language, an average of Mathematics and Language, and grade point average score.

Results Cardiorespiratory capacity and motor ability were independently associated with all academic variables in youth, even after adjustment for fitness and fatness indicators (all $P \leq .001$), whereas muscular strength was not associated with academic performance independent of the other 2 physical fitness components. In addition, the combined adverse effects of low cardiorespiratory capacity and motor ability on academic performance were observed across the risk groups (P for trend <.001).

Conclusion Cardiorespiratory capacity and motor ability, both independently and combined, may have a beneficial influence on academic performance in youth. *(J Pediatr 2014;■:■-■).*

Physical fitness is an important health marker both in the early years and later in life.[1,2] There are numerous benefits of physical fitness for physical health (ie, cardiovascular and metabolic diseases, obesity, and musculoskeletal problems) and mental health (ie, depression and anxiety).[2-8] In addition, a growing body of evidence suggests that physical fitness also may play a key role in brain health and academic performance in youths.[9-13] It is likely that physical fitness improves cognitive control that involves inhibition, working memory, and cognitive flexibility,[9,14,15] 3 aspects that provide the foundation for academic ability.[10,16]

The components of physical fitness with documented potential for improving health are cardiorespiratory capacity, muscular strength, and motor ability,[2,17] each of which may have different effects on the brain. For example, cardiorespiratory capacity is related to angiogenesis, whereas muscular strength and motor ability are associated with synaptogenesis.[18]

Previous studies have examined the association of cardiorespiratory capacity and muscular strength with academic performance separately for each component[19-22] or by summing the number of fitness tests that youth passed[23-26]; however, neither approach examined the independent contribution of each component or included motor ability, a key component of physical fitness strongly related to cognition. To the best of our knowledge, no previous study has investigated the independent and combined influence of cardiorespiratory capacity, muscular strength, and motor ability on academic performance.[27] Because these 3 components of physical fitness are highly associated with one another,[28] it is important to differentiate which components are important in relation to academic performance. This information can aid the development of targeted interventions for youth at risk for low physical fitness in these components. Thus, in the present study we examined the independent and combined associations of the 3 components of physical fitness with academic performance in youths.

Methods

Participants selected for the present study were enrolled in the UP & DOWN Study, a 3-year longitudinal study designed to assess the impact over time of

BF%	Body fat percentage
BMI	Body mass index
GPA	Grade point average
WC	Waist circumference

From the [1]Department of Physical Education, Sports and Human Movement, Autonomous University of Madrid, Madrid, Spain; [2]Department of Physical Education, School of Education, University of Cadiz, Puerto Real, Spain; and [3]Department of Family and Preventive Medicine, University of California at San Diego, La Jolla, CA

*A list of members of the UP & DOWN Study Group is available at www.jpeds.com (**Appendix**).

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physical activity and sedentary behaviors on health indicators, as well as to identify the psychoenvironmental and genetic determinants of physical activity, in a cohort of Spanish children and adolescents. Youths were recruited from schools in Cadiz and Madrid, Spain. A total of 2263 youths aged 6-18 years participated. After missing data were excluded, the present analyses included 2038 youths (90% of the original sample) with complete baseline data on physical fitness, fatness, maternal education level, and academic performance. Data were collected between September 2011 and June 2012.

Before participating in the UP & DOWN Study, parents and school supervisors were informed by letter about the purpose of the study. Written parental consent and adolescents' assent were obtained. The UP & DOWN Study was approved by the Ethics Committee of the Hospital Puerta de Hierro in Madrid and the Bioethics Committee of the Spanish National Research Council.

Socioeconomic status was assessed based on maternal educational level, reported as elementary school, middle school, high school, or university completed. Responses were dichotomized as less than university education and university education.[29]

Pubertal status was self-reported according to the 5 stages defined by Tanner and Whitehouse, based on breast development and pubic hair in girls; penis and scrotum development and pubic hair in boys.[30]

Fatness was assessed following standardized procedures.[17] The complete set of measurements was performed twice, and averages were recorded. Height and weight were measured with participants barefoot and wearing light underclothes; body mass index (BMI) was expressed as kg/m^2. BMI z-score was calculated using the Centers for Disease Control and Prevention growth charts, which are specific for age and sex (www.cdc.gov/growthcharts). Youth were categorized as nonoverweight or overweight (including obesity) according to age- and sex-specific BMI cutoff points proposed by Cole et al.[31] Waist circumference (WC) was measured at the midpoint between the lowest rib and the iliac crest. Body fat percentage (BF%) was calculated from triceps and subscapular skinfold thicknesses using the Slaughter equations.[32]

Physical Fitness

Q2 Physical fitness was assessed following the ALPHA health-related fitness test battery for youths.[17,33] All tests were performed in a single session. Muscular strength was assessed based on maximum handgrip strength and the standing long jump (lower limb explosive strength) tests. A hand dynamometer with an adjustable grip was used (TKK 5101 Grip D; Takey, Tokyo, Japan) for the handgrip strength test.[34,35] The test was performed twice, and the maximum score for each hand was recorded in kilograms. The average score of the left and right hands was calculated. The standing long jump test was performed from a starting position behind a line, standing with the feet approximately shoulder width apart. The test was performed twice, and the longer distance was recorded in centimeters.[36] A single muscular strength z-score was computed from the 2 muscular tests. The individual score of each test was standardized as follows: z-standardized value = (value − mean)/SD. The muscular strength z-score was calculated as the mean of the 2 standardized scores.[37]

Motor ability was assessed with the 4 × 10-m shuttle run test of speed of movement, agility, and coordination. The test was performed twice, and the fastest time was recorded in seconds.[36] Because the motor fitness score is inversely related to high physical fitness, it was first multiplied by −1. Cardiorespiratory capacity was assessed by the 20-m shuttle run test. The test was performed once, always at the end of the sequence. The score was the number of stages completed.[36]

Academic Performance

Academic performance was assessed through school records at the end of the academic year. Four indicators were used to define academic performance: individual grades for the core subjects (Mathematics and Language), an average of Mathematics and Language, and grade point average (GPA) score. GPA score was standardized by calculating a single average for the examinable subjects in each grade. For analytic purposes, individual letter grades were converted to numeric data: A = 5, B = 4, C = 3, D = 2, F = 1.[38-40]

Statistical Analyses

Descriptive statistics are presented as mean ± SD or n (%). Differences between sexes were tested by 1-way ANOVA for continuous variables and the χ^2 test for nominal variables. Preliminary analyses showed no significant interactions among sex, age, and physical fitness variables (all $P > .10$); thus, all analyses were performed with the total sample.

Partial correlations adjusted for sex, age, city, and pubertal status were used to examine the relationships between physical fitness and fatness indicators. The associations of the components (cardiorespiratory capacity, muscular strength, and motor ability) of physical fitness (predictor variables) with academic performance (outcomes) were analyzed by linear regression using 2 separate models. Model 1 was controlled for sex, age, city, pubertal status, and maternal education, whereas model 2 was adjusted for model 1, with the 3 physical fitness variables included simultaneously in the regression. Multicollinearity among the exposures was not found in any of the models (VIF <10). To analyze the associations of physical fitness components with academic performance independent of fatness (BMI, WC, and BF%), model 2 also controlled for fatness measurements using 4 separate models: model 2 + BMI, model 2 + BMI z-score, model 2 + WC, and model 2 + BF%. Q3

The combined analysis included those physical fitness components that showed an independent association with academic performance. Each physical fitness component was grouped into 2 categories, fit and unfit. The number of cardiorespiratory capacity stages was transformed to maximal oxygen consumption (VO_2 max, mL/kg/min) using the Lèger equation,[41] and youths were classified by the FitnessGram standards based on the healthy fitness zone for sex and age.[42] For muscular strength and motor ability, participants were categorized according the sex- and age-specific 75th percentile in the present sample. We also categorized youth by the sex- and age-specific 1 SD, and results did not change substantially; thus, findings are presented using only the 75th percentile.

Participants in the unfit category for cardiorespiratory capacity, motor ability, or muscular strength were considered in the risk factor category of each component. Youths were categorized into 3 groups according to number of fitness risk factors; those included in 2 risk factor categories (motor ability and cardiorespiratory capacity) were considered the highest-risk group, those included in 1 risk factor category (motor ability or cardiorespiratory capacity) were the medium-risk group, and those not included in any risk factor categories were the nonrisk group. Differences in academic performance based on the number of fitness risk factors was tested by 1-way ANCOVA adjusted for sex, age, city, maternal education, pubertal status, and WC. Analyses were performed using SPSS version 18.0 for Windows (IBM, Armonk, New York), with significance set at $P < .05$.

Results

[T1] Table I presents descriptive characteristics of the study sample. Overall, a higher percentage of boys than girls had mothers who achieved a university educational level (31% vs 25%; $P = .001$). Fitness levels were significantly higher in boys compared with girls (all $P < .001$). Boys had a higher WC than girls ($P < .001$), whereas girls had a higher BF% than boys ($P < .001$). Girls had higher scores than boys in Language ($P < .001$), GPA ($P < .001$), and average of Mathematics and Language ($P = .026$).

Table II (available at www.jpeds.com) presents the partial correlations of components of physical fitness and fatness after adjustment for sex, age, city, and pubertal status. Cardiorespiratory capacity and motor ability were negatively correlated with the 3 fatness variables (all $P < .001$); however, muscular strength was not associated with WC and had a negative correlation with BMI and BF % (both $P < .05$). The 3 physical fitness components were strongly related to one another (all $P < .001$). Motor ability was positively related to cardiorespiratory capacity and muscular strength ($r = 0.478$ and 0.565, respectively), and muscular strength was positively associated with cardiorespiratory capacity ($r = 0.437$).

Table III shows the association of components of [T2] physical fitness with academic performance. In model 1, the 3 physical fitness components were positively associated with all academic performance indicators after adjusting for sex, age, city, pubertal status, and maternal education (all $P < .01$). In model 2, only cardiorespiratory capacity and motor ability were independently associated with academic performance (all $P \leq .001$). Specifically, motor ability showed the strongest associations with all academic performance indicators, with standardized β values ranging from 0.158 to 0.208. For cardiorespiratory capacity, the standardized β values ranged from 0.109 to 0.136.

Table I. Descriptive characteristics for the study sample

	All	Boys	Girls	*P* for sex
Number	2038	1049	989	
Physical characteristics				
Age, y, mean ± SD	10.20 ± 3.31	10.16 ± 3.33	10.25 ± 3.28	.435
Weight, kg, mean ± SD	41.28 ± 15.80	41.98 ± 16.97	40.55 ± 14.44	.052
Height, cm, mean ± SD	142.92 ± 18.41	143.75 ± 19.61	142.05 ± 17.01	**.043** Q5
Pubertal status, I/II/III/IV/V, %	31/25/20/17/7	30/28/17/16/10	33/23/23/19/3	**<.001**
Maternal education university level, %	28	31	25	**.001**
Fatness				
BMI, kg/m^2, mean ± SD	19.42 ± 3.68	19.44 ± 3.74	19.40 ± 3.62	.861
BMI *z*-score, mean ± SD*	0.30 ± 0.97	0.35 ± 0.98	0.25 ± 0.95	**.030**
Overweight and obesity, %	30	31	30	.660
WC, cm, mean ± SD	63.16 ± 9.29	64.31 ± 9.75	61.95 ± 8.61	**<.001**
BF%, mean ± SD	21.75 ± 9.30	20.00 ± 10.35	23.60 ± 7.61	**<.001**
Physical fitness, mean ± SD				
Cardiorespiratory capacity, stage	3.87 ± 2.38	4.65 ± 2.69	3.06 ± 1.65	**<.001**
Muscular strength *z*-score†	−0.01 ± 0.88	0.25 ± 0.94	−0.27 ± 0.72	**<.001**
Motor ability, s	13.59 ± 1.89	13.25 ± 1.96	13.94 ± 1.74	**<.001**
Physical fitness risk group, %				
Low cardiorespiratory capacity	13	7	20	**<.001**
Low muscular strength	25	25	25	.920
Low motor ability	24	24	25	.622
Academic performance, mean ± SD				
Math (1-5)	3.30 ± 1.33	3.32 ± 1.33	3.28 ± 1.34	.535
Language (1-5)	3.33 ± 1.31	3.19 ± 1.35	3.47 ± 1.26	**<.001**
Math and Language (1-5)	3.31 ± 1.24	3.25 ± 1.27	3.37 ± 1.22	**.026**
GPA (1-5)	3.53 ± 0.94	3.45 ± 0.96	3.62 ± 0.91	**<.001**

*z-score calculated using growth charts developed by the Centers for Disease Control and Prevention specific for age and sex.
†z-score computed from handgrip strength and standing broad jump test.

Table III. Associations of physical fitness with academic performance in youth (n = 2038)

Predictor variables	Math		Language		Math and Language		GPA	
	β	*P*	β	*P*	β	*P*	β	*P*
Model 1								
Cardiorespiratory capacity, stage	0.199	**<.001**	0.163	**<.001**	0.193	**<.001**	0.224	**<.001**
Muscular strength *z*-score*	0.164	**<.001**	0.097	**.001**	0.139	**<.001**	0.163	**<.001**
Motor ability, s^{-1}	0.254	**<.001**	0.194	**<.001**	0.238	**<.001**	0.275	**<.001**
Model 2								
Cardiorespiratory capacity, stage	0.111	**.001**	0.109	**.001**	0.117	**<.001**	0.136	**<.001**
Muscular strength *z*-score*	0.018	.619	−0.034	.348	−0.009	.811	−0.005	.882
Motor ability, s^{-1}	0.185	**<.001**	0.158	**<.001**	0.183	**<.001**	0.208	**<.001**

Values are standardized regression coefficients (β). Model 1: Analyses were adjusted by sex, age (years), city (Cadiz/Madrid), pubertal status (stages), and maternal education (university level/below university level). Model 2: Adjustments for model 1 including the 3 physical fitness variables simultaneously.
**z*-score computed from handgrip strength and standing broad jump tests.

Table IV (available at www.jpeds.com) shows the associations among the components of physical fitness and academic performance independent of fatness. Across the 3 models, cardiorespiratory capacity and motor ability remained independently associated with all academic performance indicators after adjusting for potential confounders, including BMI, BMI *z*-score, WC, and BF%, in separate models (all $P \leq .001$). The associations of cardiorespiratory capacity and motor ability with academic performance were more attenuated when WC was included in the model than when BMI, BMI *z*-score, or BF% was included in the model. Additional analyses showed no interactions between the main exposure variables (ie, physical fitness variables) and BMI, BMI *z*-score, WC, or BF% (data not shown).

The **Figure** shows the combined influence of [F1] cardiorespiratory capacity and motor ability on academic performance, after adjusting for potential confounders. Significant differences in all academic performance variables were found across the groups (*P* for trend <.001). Indeed, the nonrisk group had significantly higher scores in all of the academic indicators compared with the medium-risk group (ranging from +0.326 to 0.378; all $P < .001$) and the highest-risk group (ranging from +0.400 to 0.529; all

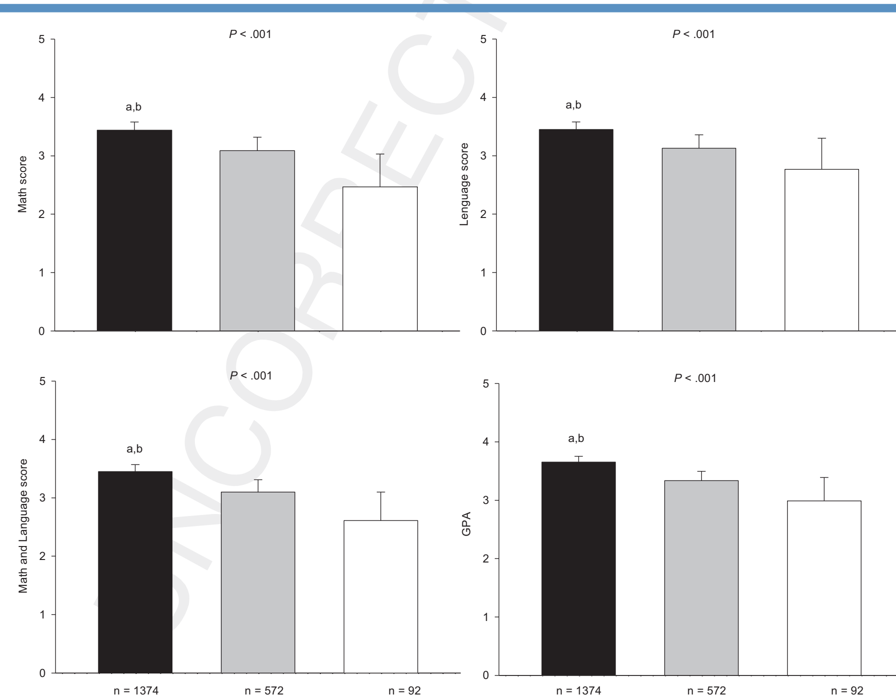

Figure. Combined influence of cardiorespiratory capacity and motor ability factors with academic performance in youth. Errors [Q4] bars represent 95% CIs. Analyses were adjusted by sex, age (years), city (Cadiz/Madrid), pubertal status (stages), maternal education (university level/below university level), in WC (cm). Risk was determined based on 1 factor (low cardiorespiratory fitness or low motor fitness) and with 2 factors (low cardiorespiratory capacity and low motor ability). [a]Significant differences between the group with 0 risk factors and the group with 1 risk factors. [b]Significant differences between the group with 0 risk factors and the group with 2 risk factors.

$P < .05$). Analyses were also performed using 4 groups (ie, no risk factors, motor ability risk factor, cardiorespiratory capacity risk factor, and both risk factors), and results were virtually similar (**Table V**; available at www.jpeds.com).

Discussion

The main findings of the present study were that cardiorespiratory capacity and motor ability, both independently and combined, were related to academic performance in youths independent of potential confounders, including fatness. In contrast, muscular strength was not associated with academic performance independent of the other 2 physical fitness components. Our findings contribute to the current knowledge by suggesting that the interdependent relationships of cardiorespiratory capacity and motor ability may have a beneficial influence on academic performance in youth.

Previous studies examined only the cardiorespiratory component in relation to cognitive indicators[10,43,44] or assessed the association of several physical fitness components with academic performance separately for each component.[19-22] Collectively, the findings of those studies reveal positive associations between cardiorespiratory capacity and academic performance,[19,21,22,45] cognitive performance,[10,20] and cognitive control among school-age children.[44] Two studies that jointly examined physical fitness components[11,26] demonstrated an association between greater cardiorespiratory capacity and higher academic performance in preadolescents[26] and children in grades 3-11[11] independent of potential confounders, including other fitness variables and BMI; however, those 2 studies did not include motor fitness, a component strongly related to cardiorespiratory capacity.[28] Our results suggest that children with greater cardiorespiratory capacity also have higher motor fitness (r = 0.48) and highlight the independent importance of each component of physical fitness in relation to academic performance.

Several mechanisms to explain the association between cardiorespiratory capacity and academic performance have been proposed. First, cardiorespiratory capacity induces angiogenesis in the motor cortex and increases blood flow. This phenomenon of improved brain vascularization could affect cognitive performance. Second, aerobic physical activity increases levels of brain-derived neurotrophic factor, which promotes neuronal survival and differentiation.[18] Finally, cardiorespiratory capacity is related to higher P3 event-related brain potential amplitude and lower P3 latency, which reflects a better ability to modulate neuroelectric indices of cognitive control.[9] These processes are involved in cognitive control, specifically in inhibition, cognitive flexibility, and working memory, which provide the basis for academic performance.[9,14,15]

In the present study, we also found that cardiorespiratory capacity was even more strongly associated with academic performance than fatness indicators. These findings imply that cardiorespiratory capacity may be more important to academic performance than fatness per se, consistent with a previous study of Texas school children.[46]

Motor ability is related to better performance in various cognitive abilities, including inhibitory control, working memory, attention, and academic performance[27]; however, the reviewed studies focused mainly on preschool-age children.[47-53] Ericsson[49] found the effect of an extension of physical education and motor training on motor ability and academic performance in children aged 6-9 years. In that intervention study, children's motor skills improved with extended physical activity and motor training, and children in the intervention groups had better performance in Swedish language (especially in reading and writing abilities) and mathematics.[49] Thus, physical activity programs that include motor training may improve motor ability as well as academic performance.[49,50]

Two different neuromechanisms could underly the association between motor ability and academic performance. First, motor skills induce syntaptogenesis, increases in brain-derived neurotrophic factor and tyrosine kinase receptors, and reorganization of movement representations within the motor cortex. Second, the spinal cord has a central role in the final common pathway for motor behavior. Thus, this set of coordinated neuronal changes related to motor ability might support improved cognitive development.[18]

In our present findings, motor ability is strongly associated with academic performance independent of fatness indicators. Likewise, the association between academic performance and physical fitness is stronger for motor fitness than for cardiorespiratory capacity. Thus, motor ability may have even greater importance for academic performance than cardiorespiratory capacity. One explanation that might partially account for the greater association of motor ability with academic performance may be the mental processing involving in motor ability. Motor tasks that represent different challenges may lead to more improvement in academic performance.[14] Another possibility could be the relevance of fine motor skills in some cognitive abilities, for example in reading or writing, which require visual control and visual and manual coordination.[51] In addition, common brain structures are used for both motor and cognitive performance, with coactivation of the neocerebellum and dorsolateral prefrontal cortex during cognitive activity.[54]

Collectively, our findings suggest the possible combined association between low cardiorespiratory capacity and motor ability and all academic performance indicators. Youths with 2 fitness risk factors had lower academic performance compared with those with either 1 or 0 risk factors; however, the low prevalence of youths with both risk factors (5%) precludes us from drawing any firm conclusions. The lack of studies analyzing the interdependent and combined influence of these fitness risk factors in youths prevents the possibility of comparing present results with others. More research is needed to examine both the independent and combined effects of cardiorespiratory and motor fitness on academic performance in youths.

Evidence regarding muscular strength and academic performance remains equivocal. Several cross-sectional studies have reported an association between muscular strength and academic performance in school-aged youths.[11,22,40,55,56] In contrast, other studies in children and adolescents found no correlation between changes in muscular strength and academic performance[21,26,57] or cognitive performance.[20,45] A longitudinal study in a large sample of 15- to 18-year-olds found no relationship between muscular strength and cognitive performance.[20] These discrepant results may be related to the aforementioned lack of adjustment of the association between muscular strength and cognition for other components of physical fitness. In the present study, muscular strength was notably associated with cardiorespiratory capacity (r = 0.44) and motor ability (r = 0.57), and our results show that the relationship between muscular strength and academic performance disappeared after controlling for cardiorespiratory capacity and motor ability. This suggests that the other 2 components of physical fitness might be more important to cognition.

Limitations of the present study include its cross-sectional design, which does not allow us to draw any conclusions on the causal direction of the associations, and its use of a convenience sample, which limits the generalizability of our findings across the population. The study has several strengths, including the relatively large and heterogeneous sample of children and adolescents and the complete and standardized assessment of physical fitness and fatness.

The association was stronger for motor ability than for cardiorespiratory capacity. This information is important, because youths who had lower levels of both cardiorespiratory capacity and motor ability had lower grades in academic subjects. Thus, high levels of cardiorespiratory and motor fitness may reduce the risk of school failure to some extent, a possibility that merits evaluation in intervention trials. Moreover, it will be important to clarify whether physical fitness improves academic performance, or whether youths with higher academic performance may be more motivated to achieve better test results. From a public health perspective, promoting physical activity that involves aerobic exercise and motor tasks during the school years to enhance cardiorespiratory capacity and motor ability may be important not only for health, but also for successful academic development and thus for potential occupational success later in life. ■

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Appendix

Members of the UP & DOWN Study Group

Spanish National Research Council, Madrid, Spain: Ascension Marcos, PhD (coordinator and principal investigator), Sonia Gomez-Martinez, PhD (scientific coordinator), Esther Nova, PhD, Esperanza L. Diaz, PhD, Belén Zapatera, MSc, Ana M. Veses, MSc, Jorge R. Mujico, PhD, and Alina Gheorghe, MSc.

Autonomous University of Madrid, Madrid, Spain: Oscar L. Veiga, PhD (principal investigator), H. Ariel Villagra, PhD, Q6 Juan del Campo, PhD, Carlos Cordente, PhD (UPM); Mario Diaz, PhD, Carlos M. Tejero, PhD, Aitor Acha, MSc, Jose M. Moya, PhD, Alberto Sanz, MSc, David Martinez-Gomez, PhD (chair), Veronica Cabanas-Sanchez, MSc, Gabriel Rodriguez-Romo, PhD (UPM), Rocio Izquierdo, MSc, Laura Garcia-Cervantes, MSc, and Irene Esteban-Cornejo, MSc.

University of Cadiz, Cadiz, Spain: José Castro-Piñero, PhD (principal investigator), Jesús Mora-Vicente, PhD, José L. González-Montesinos, PhD, Julio Conde-Caveda, PhD, Q7 Francisco B. Ortega PhD (UGR), Jonatan R. Ruiz, PhD (UGR) (cochair), Carmen Padilla Moledo, PhD, Ana Carbonell Baeza, PhD (scientific coordinator), Palma Chillón, PhD (UGR), Jorge del Rosario Fernández, MSc, Ana González Galo, MSc, Gonzalo Bellvís Guerra, MSc, Álvaro Delgado Alfonso, MSc, Fernando Parrilla, MSc, Roque Gómez, MSc, and Juan Gavala, MSc (Complutense).

University of Madrid, Madrid, Spain: Fernando Bandrés, MD, PhD (principal investigator), Alejandro Lucia, MD, Q8 PhD (UEM), Catalina Santiago, PhD (UEM) (scientific coordinator), and Felix Gómez-Gallego, PhD (UEM).

Table II. Partial correlations between physical fitness and fatness in youth (n = 2038)

	Muscular strength z-score	Motor ability, s^{-1}	BMI, kg/m^2	WC, cm	BF%
Cardiorespiratory capacity, stage	0.437*	0.478*	−0.391*	−0.333*	−0.497*
Muscular strength z-score‡	-	0.565*	−0.070†	0.017	−0.211*
Motor ability, s^{-1}		-	−0.301*	−0.246*	−0.343*
BMI, kg/m^2			-	0.867*	0.831*
WC, cm				-	0.805*
BF%					-

Analyses were adjusted for age, sex, city, and pubertal status.
*$P < .001$.
†$P < .05$.
‡z-score computed from handgrip strength and standing broad jump tests.

Table IV. Independent associations between physical fitness and academic performance independent of fatness in youth (n = 2038)

Predictor variables	Math		Language		Math and Language		GPA	
	β	*P*	β	*P*	β	*P*	β	*P*
Model 2 + BMI								
Cardiorespiratory capacity, stage	0.133	**<.001**	0.127	**<.001**	0.138	**<.001**	0.157	**<.001**
Muscular strength *z*-score*	−0.003	.941	−0.046	.217	−0.023	.532	−0.019	.600
Motor ability, s^{-1}	0.203	**<.001**	0.171	**<.001**	0.199	**<.001**	0.224	**<.001**
Model 2 + BMI *z*-score								
Cardiorespiratory capacity, stage	0.134	**<.001**	0.129	**<.001**	0.140	**<.001**	0.159	**<.001**
Muscular strength *z*-score*	0.001	.974	−0.048	.195	−0.025	.496	−0.022	.548
Motor ability, s^{-1}	0.201	**<.001**	0.172	**<.001**	0.198	**<.001**	0.224	**<.001**
Model 2 + WC								
Cardiorespiratory capacity, stage	0.129	**<.001**	0.125	**.001**	0.135	**<.001**	0.152	**<.001**
Muscular strength *z*-score*	0.001	.982	−0.049	.195	−0.025	.493	−0.021	.579
Motor ability, s^{-1}	0.200	**<.001**	0.171	**<.001**	0.197	**<.001**	0.222	**<.001**
Model 2 + BF%								
Cardiorespiratory capacity, stage	0.161	**<.001**	0.155	**<.001**	0.168	**<.001**	0.181	**<.001**
Muscular strength *z*-score*	0.007	.835	−0.045	.221	−0.020	.584	−0.015	.685
Motor ability, s^{-1}	0.207	**<.001**	0.178	**<.001**	0.204	**<.001**	0.227	**<.001**

Values are standardized regression coefficients (β).
**z*-score computed from handgrip strength and standing broad jump test.

Table V. Combined influence of cardiorespiratory and motor fitness factors with academic performance in youth

	No risk factors	Low cardiorespiratory capacity	Low motor ability	Both risk factors	*P*
Number	1374	172	400	92	
Math (1-5), mean ± SD	3.44 ± 1.27*	2.51 ± 1.34	3.34 ± 1.35	2.47 ± 1.38	**<.001**
Language (1-5), mean ± SD	3.45 ± 1.27*	2.75 ± 1.33	3.28 ± 1.33	2.75 ± 1.31	**<.001**
Math and Language (1-5), mean ± SD	3.45 ± 1.19*	2.63 ± 1.21	3.31 ± 1.28	2.61 ± 1.22	**<.001**
GPA (1-5), mean ± SD	3.65 ± 0.90*	3.10 ± 0.93	3.43 ± 0.96	2.99 ± 0.98	**<.001**

Analyses were adjusted by sex, age (years), city (Cadiz/Madrid), pubertal status (stage), maternal education (university level/below university level), and WC (cm).
†Significant differences between the group with 0 risk factors and the group with low motor ability and the group with both risk factors. Q9
*Significant differences between the group with 0 risk factors and the other 3 groups.

V

INDEPENDENT AND COMBINED INFLUENCE OF NEONATAL AND CURRENT BODY COMPOSITION ON ACADMEMIC PERFORMANCE IN YOUTH. THE UP&DOWN STUDY

Esteban-Cornejo I, Tejero-González CM, Castro-Piñero J, Conde-Caveda J, Cabanas-Sánchez V, Sallis JF, Veiga OL

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Independent and combined influence of neonatal and current body composition on academic performance in youth: The UP & DOWN Study

I. Esteban-Cornejo[1], C. M. Tejero-González[1,a], J. Castro-Piñero[2], J. Conde-Caveda[2], V. Cabánas-Sanchez[1], J. F. Sallis[3] and Óscar L. Veiga[1] on behalf of UP & DOWN Study Group*

[1]Department of Physical Education, Sports and Human Movement, Autonomous University of Madrid, Madrid, Spain; [2]Department of Physical Education, School of Education, University of Cadiz, Puerto Real, Spain; [3]Department of Family and Preventive Medicine, University California, San Diego, CA, USA

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Summary

Backgrounds: Unhealthy body composition is a cause for concern across the lifespan.

Objective: The objective of this study was to examine the independent and combined associations between neonatal and current body composition with academic performance among youth.

Methods: This cross-sectional study was conducted with a total of 1557 youth (745 girls) aged 10.4 ± 3.4 years. Birth weight and length at birth were self-reported. Current body composition was assessed by body mass index (BMI), waist circumference (WC) and percentage of body fat (BF%). Academic performance was assessed through schools records.

Results: Birth weight was related to all academic variables in boys, independent of potential confounders, including BMI; whereas WC, BMI and BF% were related to all academic performance indicators in both boys and girls, independent of potential confounders, including birth weight (all $P < 0.05$). In addition, the combined adverse effects of low birth weight and current overweight on academic performance were observed in both boys and girls for grade point average (GPA) indicator. Boys in the group with none adverse effect had significantly higher scores in GPA (score +0.535; 95% confidence interval, 0.082–0.989) than boys in the group of both adverse effects ($P < 0.007$); among girls, GPA score was higher in the group with none adverse effect than in the groups with one or two adverse effects (P for trend = 0.029).

Conclusions: Neonatal and current body composition, both independently and combined, may influence academic performance in youth.

Keywords: Academic performance and youth, birth weight, body composition, overweight.

Address for correspondence: Ms Irene Esteban-Cornejo, Department of Physical Education, Sports and Human Movement, Universidad Autónoma de Madrid, Ctra de Colmenar km 15, 28049 Madrid, Spain. E-mail: irene.esteban@uam.es

*The UP & DOWN Study Group

Coordinator: Ascension Marcos. *Principal Investigators*: Ascension Marcos, Oscar L. Veiga, Jose Castro-Piñero, and Fernando Bandrés. *Scientific Coordinators*: David Martinez-Gomez (chair), Jonatan R. Ruiz (co-chair), Ana Carbonell-Baeza, Sonia Gomez-Martinez, and Catalina Santiago. *Spanish National Research Council:* Ascension Marcos, Sonia Gomez-Martinez, Esther Nova, Esperanza L. Diaz, Belén Zapatera, Ana M. Veses, Jorge R. Mujico, and Alina Gheorghe. *Autonomous University of Madrid*: Oscar L. Veiga, H. Ariel Villagra, Juan del-Campo, Carlos Cordente (UPM), Mario Diaz, Carlos M. Tejero, Aitor Acha, Jose M. Moya, Alberto Sanz, David Martinez-Gomez, Veronica Cabanas-Sanchez, Gabriel Rodriguez-Romo (UPM), Rocio Izquierdo, Laura Garcia-Cervantes, and Irene Esteban-Cornejo. *University of Cadiz*: José Castro-Piñero, Jesús Mora-Vicente, José L. González-Montesinos, Julio Conde-Caveda, Francisco B. Ortega (UGR), Jonatan R. Ruiz (UGR), Carmen Padilla Moledo, Ana Carbonell-Baeza, Palma Chillón (UGR), Jorge del Rosario Fernández, Ana González Galo, Gonzalo Bellvís Guerra, Álvaro Delgado Alfonso, Fernando Parrilla, Roque Gómez, and Juan Gavala. *Complutense University of Madrid*: Fernando Bandrés, Alejandro Lucia (UEM), Catalina Santiago (UEM), and Felix Gómez-Gallego (UEM).

Introduction

Unhealthy body composition is a cause for concern across the lifespan (1–3). Low weight at birth has been identified as a risk factor for metabolic disorders, adiposity and cognitive impairments later in life (2–4). Likewise, youth obesity is associated with chronic diseases, mental health problems and cognitive decline (5–7). Indeed, both low birth weight (LBW) and obesity might have a negative influence on academic performance.

A growing body of literature suggests that LBW may play a negative role in cognitive development (3). It is likely poor neurodevelopmental outcomes of LBW infants may result from either perinatal morbidity or postnatal growth and development (8), which in turn, affect academic performance at school age (9–11). From 15 to 34% of LBW youth obtained poor academic performance (9), affecting mainly math and reading areas (10,11).

Obesity might have a detrimental effect on academic performance during childhood and adolescence (12–16). For example, higher body mass index (BMI), body fat and abdominal fat mass were associated with poor academic performance in children (12). In addition, obese adolescents obtained lower academic performance score than healthy-weight adolescents (15). Although obesity and LBW are related to academic performance, to our knowledge, to date there is no study investigating the independent and combined influence of these two aspects of body composition on academic performance.

The present study examined the independent and combined associations between neonatal and current body composition with multiple indicators of academic performance among youth.

Methods

Participants were recruited from the UP & DOWN study. This is a 3-year longitudinal study designed to assess the impact, over time, of physical activity and sedentary behaviours on health indicators as well as to identify the psycho-environmental and genetic determinants of physical activity in a convenience sample of Spanish children and adolescents. Data collection was undertaken from September 2011 to June 2012. Children and adolescents were recruited from schools in Cadiz and Madrid, respectively. A total of 2263 youth aged 10.4 ± 3.4 years participated in the UP & DOWN study. The present study included 812 boys and 745 girls (*n* = 1557 youth) with complete data at baseline on neonatal characteristics, maternal education level, neonatal body composition, current body composition and academic performance (69% of the original sample).

Parents and school supervisors were informed through a letter about the study, and written informed consent was provided. The UP & DOWN study protocols were approved by the Ethics Committee of the Hospital Puerta de Hierro (Madrid, Spain) and the Bioethics Committee of the National Research Council (Madrid, Spain).

Neonatal characteristics

Gestational age and trimester of birth were self-reported by parents. Gestational age at time of delivery was reported as a continuous variable (weeks). The trimester of birth was defined by month of birth date in four categories: first (January–March), second (April–June), third (July–September) and fourth (October–December) trimester.

Maternal education level

The socioeconomic status was defined by the maternal educational level reported as elementary school, middle school, high school and university. Answers were dichotomized as below university education and university education (17).

Neonatal body composition

Birth weight and length at birth were self-reported by parents. Two neonatal body compositions indexes were calculated. BMI at birth was calculated as birth weight in kilograms divided by birth length in meters squared (kg m^{-2}). Ponderal index (PI) was computed as birth weight in kilograms divided by birth length in meters cubed (kg m^{-3}). LBW participants were defined as those with birth weight ≤2.5 kg (18).

Current body composition

Current body composition was assessed following standardized procedures (19). The complete set of measurements was performed twice and averages were recorded. BMI and waist circumference (WC) were determined. Body fat percentage (BF%) was calculated from triceps and subscapular skinfold thicknesses using Slaughter's equations (20). Fat-free mass (FFM), in kilograms was estimated by subtracting fat mass (BF% multiplied by weight) from total body weight (20).Overweight (including obese) youth were classified according to international age- and sex-specific BMI cut-offs proposed by Cole *et al*. (21).

Academic performance

Academic performance was assessed through school records at the end of the academic year. Academic performance was based on four indicators: individual grades for the core subjects (Mathematics and Language), an average of Mathematics and Language (MLA) and grade point average (GPA) score. GPA score was standardized by calculating a single average for the examinable subjects in each grade. Previously, for analytic purposes, individualletter grades were converted to numeric data: A = 5, B = 4, C = 3, D = 2, F = 1.

Statistical analysis

Descriptive statistics are presented as mean (standard deviation) or percentages. Differences between sexes were tested by one-way analysis of variance and chi-squared tests for continuous and nominal variables, respectively. Preliminary analyses showed a significant interaction between sex and birth weight ($P < 0.001$); therefore, all analyses were performed separately for boys and girls.

The independent associations between neonatal body composition (birth weight, birth BMI and PI at birth) and current body composition (actual BMI, WC and BF%) with academic performance were analysed by linear regression using two separate models: model 1 was controlled for age, city, gestational week, trimester of birth and FFM; model 2 was additionally controlled for maternal education. In both models, we mutually adjusted exposures (neonatal body composition and current body composition). That is, when neonatal body composition variables were modelled as the main exposures, the analysis was adjusted for BMI, and when current body composition variables were modelled as the main exposures, the analysis was adjusted for birth weight. Each body composition variable was examined in a different regression model.

The combined association of neonatal and current body composition risk factors (i.e. LBW and overweigh/obesity, respectively) with academic performance was analysed by one-way analysis of covariance adjusted for age, city, gestational week, trimester of birth, FFM and maternal education. Analyses were performed with the IBM SPSS Statistics 18.0 for Windows and the level of significance was set to 0.05.

Results

Table 1 shows the descriptive characteristics of the study sample. Boys had higher birth weights than girls ($P < 0.001$), and 6% of the boys and 10% of the girls were categorized as LBW ($P = 0.022$). Moreover, boys had higher WC and FFM than girls, and levels of BF% were higher for girls than for boys (all $P < 0.001$). Girls had higher scores than boys in Language ($P < 0.001$) and GPA ($P = 0.001$).

Table 2 shows the independent association of neonatal and current body composition with academic performance. In model 1, birth weight of boys was positively associated with all academic performance variables, after adjusting for potential confounders, including BMI (all $P \leq 0.02$). Significant associations between all current body composition variables with academic performance were found for both, boys and girls, after controlling for confounders including birth weight (model 1). Among boys, BMI, WC and BF% were negatively related to all academic performance variables (all $P < 0.001$; all $P < 0.03$ and all $P < 0.036$, respectively). Among girls, BMI, WC and BF% were inversely associated with all academic performance variables (all $P < 0.001$; all $P \leq 0.001$ and all $P \leq 0.004$, respectively). In model 2, these associations remained significant after further adjustment for maternal education (all $P < 0.05$) with the exception in boys for which the relationship between WC and Language score became marginal ($P = 0.073$), and the associations of BF% with Math, Language and MLA scores became non-significant.

Figure 1 presents the combined influence of neonatal and current body composition with academic performance, after adjusting for potentialconfounders. Youth were categorized into three groups according to the number of body composition risk factors: zero risk factors, one risk factor (overweight/obesity or LBW) and two risk factors (overweight/obesity and LBW). Among boys, significant differences in all academic performance variables were found across the risk factor groups (P for trend < 0.05). In addition, boys in the group with 0 risk factors had significantly higher scores in Language (score +0.719; 95% confidence interval [CI], 0.069–1.368), MLA (score +0.618; 95% CI, 0.025–1.210) and GPA (score +0.535; 95% CI, 0.082–0.989) than boys in the group of two risk factors (all $P < 0.05$). Among girls, GPA score was higher in the group with 0 risk factors than in the groups with one or two risk factors (P for trend = 0.029).

Discussion

The main findings in this study showed that neonatal and current body composition, both independently and combined, were associated with academic

Table 1 Characteristics of study sample

	All	Boys	Girls	*P* for sex
n	1557	812	745	
Physical characteristics				
Age (years)	10 ± 3.3	10.0 ± 3.3	10.2 ± 3.3	0.081
Weight (kg)	40.8 ± 16.0	41.2 ± 17.1	40.5 ± 14.6	0.389
Height (cm)	142.2 ± 18.6	142.5 ± 19.7	141.8 ± 17.3	0.435
Neonatal characteristics				
Gestational age (weeks)	38.9 ± 2.4	38.8 ± 2.3	38.9 ± 2.5	0.357
Trimester of birth (quarter)	2.5 ± 1.1	2.5 ± 1.1	2.4 ± 1.1	0.100
Maternal education level university (%)	30	33	27	**0.018**
Neonatal body composition				
Birth weight (kg)	3.3 ± 0.5	3.3 ± 0.5	3.2 ± 0.5	<**0.001**
Birth body mass index (kg m^{-2})	13.0 ± 3.4	13.1 ± 3.2	13.0 ± 3.6	0.601
Ponderal index at birth (kg m^{-3})	26.5 ± 15.0	26.2 ± 15.0	26.7 ± 14.8	0.503
Low birth weight [≤2.50 kg] (%)	8	6	10	**0.022**
Current body composition				
Body mass index (kg m^{-2})	19.4 ± 3.7	19.4 ± 3.7	19.4 ± 3.6	0.785
Waist circumference (cm)	62.9 ± 9.4	64.0 ± 9.9	61.90 ± 8.7	<**0.001**
Body fat (%)	21.8 ± 9.4	20.2 ± 10.4	23.7 ± 7.6	<**0.001**
Fat-free mass (kg)	31.2 ± 11.0	32.0 ± 12.2	30.3 ± 9.4	<**0.001**
Overweight + obesity (%)	34	36	33	0.259
Academic performance				
Math (1–5)	3.46 ± 1.28	3.50 ± 1.26	3.43 ± 1.30	0.323
Language (1–5)	3.47 ± 1.27	3.36 ± 1.30	3.59 ± 1.22	<**0.001**
Math and Language (1–5)	3.47 ± 1.20	3.43 ± 1.21	3.51 ± 1.18	0.183
Grade point average (1–5)	3.66 ± 0.90	3.58 ± 0.90	3.73 ± 0.86	**0.001**

Values are mean ± standard deviation or percentages.

performance in youth. Neonatal body composition was related to academic performance in boys, independent of potential confounders, including BMI; whereas current body composition was related to academic performance in both boys and girls, independent of potential confounders, including birth weight. In addition, the combined adverse effects of LBW and current overweight on academic performance were observed in both boys and girls. These novel results contribute to a growing body of evidence by suggesting that an unhealthy body composition across the lifespan may have a negative effect on academic performance in youth.

Experimental evidence in neuroscience supports the present observed association between academic performance and multiple body composition indicators at birth and throughout the whole course of life (16,22). Brain development is highly susceptible to the consequences of preterm birth (23). A recent study using magnetic resonance imaging showed that LBW was associated with smaller brain volumes. Particularly, reduced volume of midbrain structures, the caudate and corpus callosum, which are involved in connectivity, executive attention and motor control. These brain abnormalities, in turn, were related to poor academic performance (24). Others neuroimaging studies indicated that obesity was associated with detectable structural differences in the brain in youth as well as in younger adults (25,26). Prefrontal cortex is a brain region involved in cognitive control, and thus in subsequent academic performance (27). Gray matter reductions in prefrontal cortex appear to occur in a dose-dependent manner with increasing BMI (27,28). Therefore, unhealthy body composition from birth through adolescence might induce an important impairment that hampers learning and academic performance.

In the present study, birth weight was positively associated with academic performance, thus LBW youth had lower academic performance. However, this influence showed a sex effect, and only LBW boys had lower values in all of the academic indicators, independent of current BMI. To our knowledge, this is the first study showing the independent and combined associations of neonatal and current body

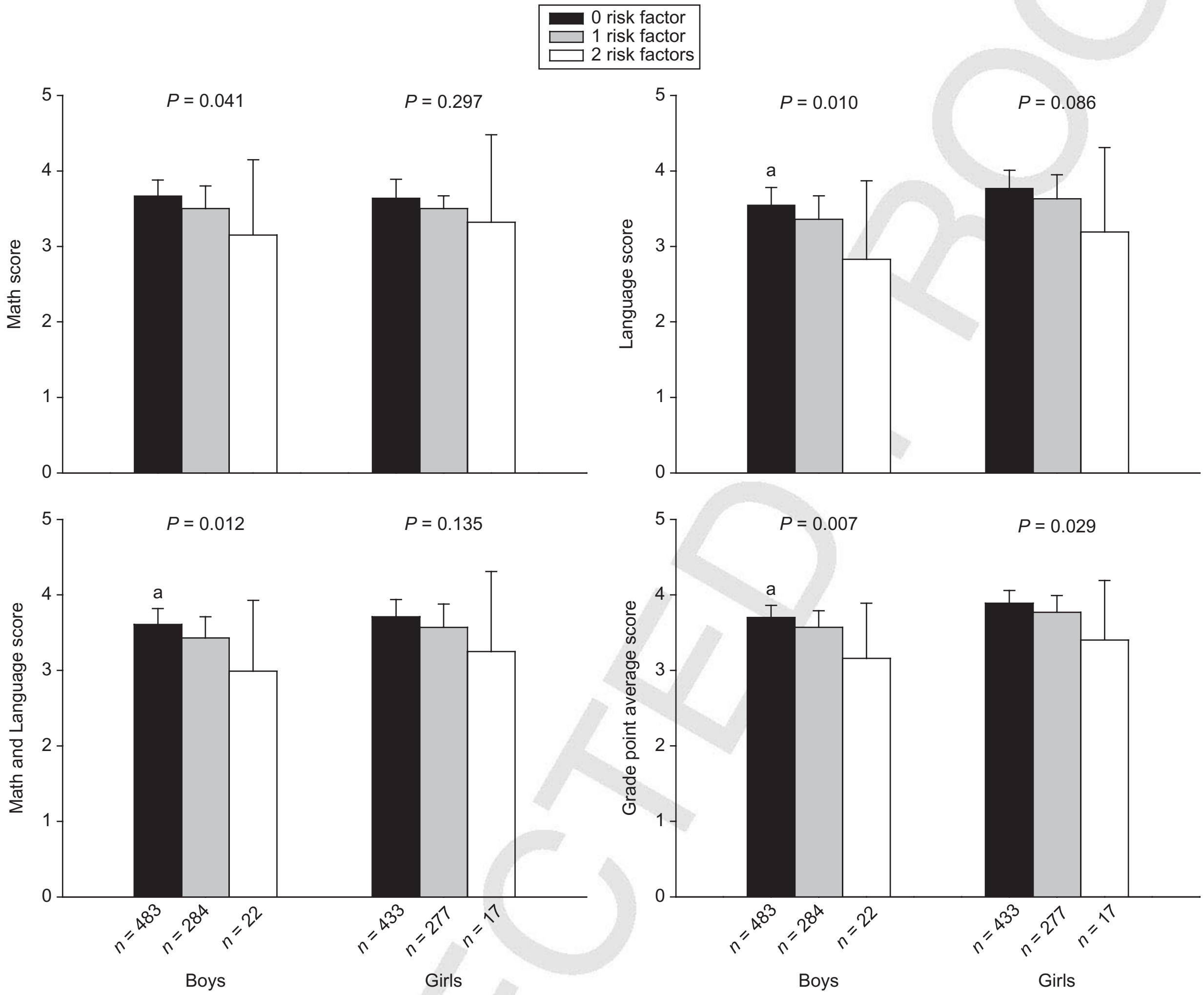

Figure 1 Combined influence of neonatal and current body composition factors with academic performance in youth. Errors bars represent 95% confidence intervals; analyses were adjusted by age (years), city (Cadiz/Madrid), gestational age (week), trimester of birth (quarter), fat-free mass (kg) and maternal education (university level/below university level). Risk factors computed as having one factor (overweight/obesity or low birth weight) and having two factors (overweight/obesity and low birth weight). [a]Significantly different between the group having zero risk factors and the group having two risk factors.

composition with academic performance, which hampers comparisons with other studies. Taken together, almost all studies that examined associations between birth weight and cognitive outcomes in youth showed significant associations with boys and girls together (9–11,29). The sex-specific effect observed in our study concurs with that in other studies (18,30–32). Johnson *et al*. showed an increased risk for learning disabilities in LBW boys, but not LBW girls (18). Other studies demonstrated the larger effects of LBW for boys on general intelligence (30), visual attention (31) and executive function (32).

The factors underlying this interaction between sex and birth weight remain to be determined. A possible explanation might be that the sex of the foetus may produce different responses to variations in maternal nutrition (33). It is likely that a pregnant woman carrying a male embryo had higher energy intake than a pregnant woman carrying a female embryo, and as such, maternal nutrition might influence foetal growth (34). In our findings, boys were 100 g heavier than girls and gestational age did not differ between boys and girls. Thus, boys grew more rapidly in prenatal development, and as such, they may be more susceptible to the influences of nutritional variation during gestation (31). It is reasonable to suppose that a similar nutritional mechanism might influence the prenatal development of the brain, which may explain why variations in birth weight among boys are

Table 2 Independent association of neonatal and current body composition with academic performance in youth

	Math				Language				Math and Language				Grade point average			
	Model 1		Model 2		Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
	β	*P*	β	*P*	β	*P*	β	*P*	β	*P*	β	*P*	β	*P*	β	*P*
Boys (*n* = 812)																
Neonatal body composition																
Birth weight (kg)	0.089	**0.014**	0.082	**0.020**	0.107	**0.003**	0.100	**0.005**	0.104	**0.004**	0.097	**0.006**	0.086	**0.019**	0.079	**0.028**
Birth BMI (kg m^{-2})	–0.022	0.514	–0.022	0.496	–0.008	0.819	–0.008	0.804	–0.015	0.642	–0.016	0.622	–0.005	0.882	–0.006	0.867
PI at birth (kg m^{-3})	–0.049	0.135	–0.052	0.107	–0.042	0.207	–0.045	0.168	–0.049	0.141	–0.051	0.109	–0.032	0.341	–0.035	0.286
Current body composition																
BMI (kg m^{-2})	–0.137	**<0.001**	–0.100	**0.010**	–0.129	**0.001**	–0.090	**0.022**	–0.141	**<0.001**	–0.101	**0.009**	–0.168	**<0.001**	–0.127	**0.001**
Waist circumference (cm)	–0.134	**0.003**	–0.100	**0.024**	–0.117	**0.011**	–0.081	0.073	–0.133	**0.003**	–0.096	**0.030**	–0.174	**<0.001**	–0.136	**0.003**
Body fat (%)	–0.078	**0.020**	–0.051	0.118	–0.071	**0.036**	–0.043	0.193	–0.079	**0.018**	–0.050	0.125	0.107	**0.002**	–0.077	**0.021**
Girls (*n* = 745)																
Neonatal body composition																
Birth weight (kg)	–0.022	0.588	–0.014	0.715	–0.037	0.359	–0.030	0.453	–0.031	0.434	–0.023	0.548	–0.016	0.691	–0.007	0.857
Birth BMI (kg m^{-2})	–0.019	0.583	–0.009	0.803	0.001	0.976	0.012	0.734	–0.010	0.776	0.001	0.966	–0.003	0.932	0.010	0.768
PI at birth (kg m^{-3})	–0.016	0.634	–0.007	0.833	0.011	0.765	0.020	0.562	–0.004	0.918	0.006	0.848	0.002	0.955	0.014	0.690
Current body composition																
BMI (kg m^{-2})	–0.220	**<0.001**	–0.190	**<0.001**	–0.216	**<0.001**	–0.186	**0.001**	–0.233	**<0.001**	–0.200	**<0.001**	–0.258	**<0.001**	–0.221	**<0.001**
Waist circumference (cm)	–0.194	**0.001**	–0.162	**0.005**	–0.237	**<0.001**	–0.205	**<0.001**	–0.230	**<0.001**	–0.195	**0.001**	–0.249	**<0.001**	–0.209	**<0.001**
Body fat (%)	–0.124	**0.002**	–0.110	**0.006**	–0.119	**0.004**	–0.105	**0.010**	–0.130	**0.002**	–0.115	**0.004**	–0.164	**<0.001**	–0.146	**<0.001**

Values are standardized regression coefficients (β). BMI, body mass index; PI, ponderal index. Model 1: analyses were adjusted by age (years), city (Cadiz/Madrid), gestational age (weeks), trimester of birth (quarter), fat-free mass (kg). Neonatal body composition controlling for BMI and current body composition controlling for birth weight. Model 2: adjustments for model 1 plus maternal education (university level/below university level).

more strongly related to later cognitive outcomes than among girls. Future studies should clarify the mechanisms that induce the sex effect found in our study.

Another finding from the current study showed that the inverse association of current BMI, WC and BF% with academic performance were stronger for girls than boys, after controlling for potential confounders including birth weight and maternal education. A possible explanation is that the self-esteem of girls may be more adversely affected by overweight, which in turn, may affect academic performance (13). There are several studies showing that current body composition was negatively associated with academic performance (12–15,35); however just one study included birth weight as a covariate (14). For example, Sigfusdottir *et cal.* found that BMI was associated with lower grades after controlling for SES and other personal factors in a sample of Icelandic schoolchildren aged 14–15 years (35). Another study found that overweight children had lower scores on math and reading tests than non-overweight peers, and controlling for SES and other potential confounders, including birth weight, weakened the associations (14). As well, Sabia indicated a negative relationship between BMI and GPA for white girls aged 14–17 (13).

The studies cited earlier only assessed current body composition through BMI. Paradoxically, BMI may be the least accurate indicator of body composition, because the height and weight relationship varies dramatically during growth, which might underestimate or confuse the association between current body composition and academic performance during childhood and adolescence (12). Kamijo *et al.* supplemented BMI with more accurate measures of adiposity (i.e. whole body fat and abdominal fat mass measured using dual X-ray absorptiometry), and indicated that higher levels of central adiposity were more robustly related to lower cognition in children aged 7–9 years (12). Similarly, the present study supplemented BMI with WC and BF%, and showed BMI and WC were more robustly associated with academic performance than BF%. It is possible that variations among studies are due to the different methods used to assess current body composition and academic performance as well as the specific age ranges within studies. Thus, further longitudinal studies in a larger sample of youth are necessary to examine the relationship between current body composition and academic performance independently of birth weight, as well as other relevant confounders previously identified in the literature (e.g. headache) (36), using more accurate measures.

In the analyses of combined effects, we observed a negative association of being both LBW and overweight in all academic performance indicators for boys, and in GPA score for girls. Youth, having the two risk factors, had lower academic performance compared with those with either one or zero risk factors. These findings suggested the possible combined effect of being LBW and overweight on academic performance. However, the low prevalence of youth with both risk factors (3% of boys and 2% of girls) precludes drawing any firm conclusions. The lack of studies analysing the combined effect of these risk factors in youth prevents the possibility of comparing our results with others. More research is warranted examining both the individual and the combined effect of neonatal and current body composition on academic performance in young people.

Limitations of the present study include its cross-sectional design, which precludes drawing conclusions on the direction of the associations. A second limitation was that neonatal variables were self-reported, so findings must be interpreted with caution. Future research using medical records of neonatal variables may provide insights. Grades are socially valid measures of academic achievement, but they have potential limitations of bias, so studies are recommended using standardized achievement tests and measures of brain function. The present study had several strengths such as the relatively large sample of children and adolescents, the complete and objective assessment of current body composition, and the inclusion of several relevant confounders, such as maternal education, FFM, trimester of birth, birth weight and BMI, which have not all been included in previous research on this topic.

In summary, the results of the present study suggest that both neonatal and current body composition are independently associated with academic performance in boys, and current body composition is related to academic performance in girls.

In addition, results suggested the combination of LBW and overweight was associated with a lower academic performance in youth. Our results are of importance because the consequences of neonatal body composition tend to continue into childhood and adolescence. An unhealthy body composition in youth increases the risk of failing in academic performance, and as adults, decreases the occupational success (11).

Therefore, educational and public health policies promoting ongoing intervention during the early years of school to enhance youth skills and to prevent obesity may be essential for successful development in the academic and health spheres as well as for the associated consequences to cope with general life.

Conflict of interest statement

No conflict of interest was declared.

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Authors contributions

IEC had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design*: IEC, CMTG and ÓLV. *Acquisition of data*: IEC, ÓLV, CMTG, JCC, JCP and VCS. *Analysis and interpretation of data*: IEC, JFS, CMTG and ÓLV. *Drafting of the paper*: IEC. *Critical revision of the paper for important intellectual content*: IEC, ÓLV, CMTG, JFS, JCC, JCP and VCS. *Statistical analysis*: IEC, JFS, CMTG and ÓLV. *Obtained funding*: ÓLV. *Study supervision*: ÓLV, JFS and CMTG.

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ORIGINAL RESEARCH

XI. CONCLUSIONS

- Physical activity is associated with cognition, but more research is needed to clarify the role of sex, intensity and type of physical activity, and some psychological variables in this association
- Objectively measured physical activity is related to academic performance in both children and adolescents, but the magnitude of this association, albeit negatively significant, was very weak.
- Maternal physical activity before and during pregnancy is associated with youth's academic performance. Continuing maternal physical activity practice during pregnancy is associated with greater benefits for youth's academic performance.
- Cardiorespiratory and motor fitness, both independently and combined, are related to academic performance in youth.
- Neonatal and current body composition, both independently and combined, are associated with academic performance in youth.

XII. CONCLUSIONES

- La actividad física está asociada con la cognición, pero se necesita más investigación para clarificar el rol del sexo, la intensidad y el tipo de actividad física y algunas variables psicológicas en esta asociación.
- La actividad física medida por acelerometría se asocia con el rendimiento académico de los jóvenes, pero la magnitud de esta asociación, aunque negativa, es muy débil.
- La actividad física de la madre antes y durante el embarazo está asociada con el rendimiento académico de los jóvenes. Continuar la práctica de actividad física materna durante el embarazo puede tener mayores beneficios para el rendimiento académico de los jóvenes.
- La capacidad cardiorespiratoria y la habilidad motora, tanto independientemente como en combinación, se asocia con el rendimiento académico de los niños y adolescentes.
- La composición corporal neonatal y actual, tanto independientemente como en combinación, está asociada con el rendimiento académico en los jóvenes.

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XIV. CURRICULUM VITAE

Irene Esteban Cornejo, MSc

Birthday date: 26/February/1988.

Position: Pre-doctoral research fellow.

Affiliation: Department of Physical Education, Sport and Human Movement, University Autonomous of Madrid, Madrid, Spain.

E-mail: irene.esteban@uam.es

ACADEMIC BACKGROUND

- 2012 / 2014 — PhD Student in **Physical Activity and Sport Sciences**, University Autonomous of Madrid, Madrid, Spain.
- 2010 / 2011 — Master´s degree in **Training for Secondary, Professional Training and Languages teachers,** University Autonomous of Madrid, Madrid, Spain.
- 2010 / 2011 — Master´s degree in **Business Management,** National University of Distance Education, Madrid, Spain.
- 2006 / 2010 — Bachelor´s degree in **Physical Activities Sciences and Sport,** University Autonomous of Madrid, Madrid, Spain.

PREVIOUS POSITIONS

- 2012 / 2012 — **Spanish Sport Council grant.** Department of Physical Education, Sport and Human Movement, University Autonomous of Madrid, Madrid, Spain, 2012.
- 2009 / 2010 — **ERASMUS student exchange grant.** School of Psychology and Sport Science, Northumbria University, Newcastle, England.

BRIEF STAYS IN INTERNATIONAL RESEARCH GROUPS

- 2013 June / September —Departament of Family and Preventive Medicine, Active Living research. **University of California San Diego.** San Diego, CA, USA. Advisor: James F. Sallis PhD.
- 2014 May —Departament of Family and Preventive Medicine, Active Living research. **University of California San Diego.** San Diego, CA, USA. Advisor: James F. Sallis PhD.

RESEARCH PROJECTS

- The **UP&DOWN** study: Follow-up in healthy schoolchildren and in adolescents with Down syndrome: psycho environmental and genetic determinants of physical activity and its impact on fitness, cardiovascular diseases, inflammatory biomarkers and mental health.
- The **PHYSICAL ACTIVITY MONITORING SYSTEM** study: Development of a pilot system of monitoring health-related physical activity/fitness and sedentary behavior in school population.

ARTICLES IN JCR JOURNALS

- **Esteban-Cornejo I**, Tejero-González C, Sallis JF, Veiga OL. Physical activity and congniton in adolescents. A systematic review. Journal of Science and Medicine in Sport. *Proposed to be accepted.*

- **Esteban-Cornejo I,** Marcos A, Tejero-González C, Castillo R; Lanza-Saiz R; Vicente-Rodriguez G, Gómez-Martínez S, Martínez-Gómez D. Characteristics of extracurricular physical activity and cognitive performance in adolescents. The AVENA Study. Journal of Sports Sciences. 2014 Apr 29:1-8. [Epub ahead of print]

- **Esteban-Cornejo I**, Tejero-González C , Castro-Piñero J, Conde-Caveda J, Cabánas-Sanchez V, Sallis JF, Veiga OL. Independent and combined influence of neonatal and current body composition on academic performance in youth. The UP & DOWN Study. Pediatrics Obesity. *In press.*

- **Esteban-Cornejo I**, Tejero-González C, Martínez-Gómez D, Del-Campo J, González-Galo A, Padilla-Moledo C, Sallis JF, Veiga OL. Independent and combined influence of the components of physical fitness on academic performance in youth. The Journal of Pediatrics. *In press.*

- **Esteban-Cornejo I**, Tejero-González C, Martínez-Gómez D, Conde-Caveda J, Fernanez J, Cabánas-Sanchez V , Sallis JF, Veiga OL. Objectively measured physical activity and academic performance in youth. The UP & DOWN Study Acta Paediatrica. *Proposed to be accepted.*

- **Esteban-Cornejo I**, Martínez-Gómez D, Tejero-González C, Castro-Piñero J, Carbonell-Baeza A, Izquierdo-Gómez R, Sallis JF, Veiga OL. Maternal physical activity during the prenatal period and the offspring's academic performance in youth. The UP & DOWN Study American Journal of Human Biology. *Under review.*

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- Veses A, Gomez-Martinez, S Perez de Heredia F, **Esteban-Cornejo I**, Castillo, R, Estecha S, Garcia-Fuentes M , Veiga OL; Calle; ME, Marcos A. Cognition and the risk of eating disorders in Spanish adolescents: The AVENA & AFINOS Studies. European Journal of Pediatrics. *Submitted.*

- Fraile-García J, Tejero-González C, **Esteban-Cornejo I,** Veiga OL. Factors associated with physical education academic performance: enjoyment, motor self-efficacy and physical activity-sport levels. Revista de educación. *Submitted.*

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- Cañadas L, Ruiz JR, Gomez-Martínez S, **Esteban-Cornejo I,** Pérez-Llamas F, Casajús JA, Marcos A, Martínez-Gómez D. Obese and unfit students dislike physical education in adolescents. myth or truth?: The AVENA and UP&DOWN Studies. *In manuscript.*

PUBLICATIONS IN CONGRESSES

- **IV International Congress of Physical Education and Sport Science** – VII Nutrition, Medicine and Performance National Seminar, Pontevedra, Spain. May/ 10-11-12/ 2012.

  - Izquierdo-Gómez, R.; **Esteban-Cornejo, I**.; García-Cervantes, L.; Cabanas-Sánchez, V. ; Sanz, A. y Veiga Nuñez, O.L. (2012, mayo). *Fiabilidad del cuestionario de estilos de vida activos y sedentarios para padres de adolescente con discapacidad intelectual y síndrome de down.* En Actas del IV Congreso Nacional de Ciencias del Deporte y la Educación Física – VII Seminario Nacional de Nutrición, Medicina y Rendimiento Universidad de Vigo. Pontevedra. España.

  - García-Cervantes, L.; Cabanas-Sánchez, V. ; Izquierdo-Gómez, R.; **Esteban-Cornejo, I.** y Veiga Nuñez, O.L. (2012, mayo). *Correlatos ambientales de la actividad física en niños y adolescentes. Una revisión.* En Actas del IV Congreso Nacional de Ciencias del Deporte y la Educación Física – VII Seminario Nacional de Nutrición, Medicina y Rendimiento Universidad de Vigo. Pontevedra. España.

- **Esteban-Cornejo, I**.; García-Cervantes, L.; Cabanas-Sánchez, V. e Izquierdo-Gómez, R. (2012, mayo). *La expresión corporal como intervención en la satisfacción hacia la Educación Física.* En Actas del IV Congreso Nacional de Ciencias del Deporte y la Educación Física – VII Seminario Nacional de Nutrición, Medicina y Rendimiento Universidad de Vigo. Pontevedra. España.

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- **III EXERNET Congress and II INEF Postgraduates Convention.** Madrid, Spain. October/ 26 -27/ 2012.

  - Cabanas-Sánchez, V.; **Esteban-Cornejo, I**.; Izquierdo-Gómez, R.; García-Cervantes, L.;Veiga Nuñez, O.L. y ; Tejero- González, C (2012,octubre). Hábitos activos y sedentarios y su correlación con el rendimiento académico. Póster presentado al III Congreso EXERNET y II Convención de Postgradudados del INEF. Madrid. España.

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- **VII International Congress of Sport Science Spanish Association.** Granada, Spain. November /15-16-17/ 2012.

  - Izquierdo-Gómez, R.; García-Cervantes, L.; Cabanas-Sánchez, V.; **Esteban-Cornejo, I**.; Cueto-Díaz, M. y Veiga Nuñez, O.L. (2012, noviembre). *Physical activity measurement in individuals with down syndrome: A literature review.* Actas del **VII Congreso Internacional de la Asociación Española de Ciencias del Deporte,** Granada. España.

- **Esteban-Cornejo, I**.; Izquierdo-Gómez, R.; García-Cervantes, L.; Cabanas-Sánchez, V.; Tejero-González, C y Veiga Nuñez, O.L. (2012, noviembre). *Academic performance and physical activity in adolescents: Associations and measures. A systematic review.* En Actas del **VII Congreso Internacional de la Asociación Española de Ciencias del Deporte,** Granada. España.

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- **International Society of Behavioral Nutrition and Physical Activity Congress.** San Diego, California. USA. May /21-24/ 2014.

  - **Esteban-Cornejo I**, Tejero-González C, Del-Campo J, González-Galo A, Padilla-Moledo C, Sallis JF , Martínez-Gómez D (2014, May). *Independent and combined influence of the components of physical fitness on academic performance in youth: The UP & DOWN Study*. En actas del **International Society of Behavioral Nutrition and Physical Activity Congress**

XV. ACKNOWLEDGEMENTS

When you take a road, you never know if it is going to be correct, but the only option to discover it is putting your fingerprints on it... just so you know if you got it. Looking back, I can see my footprints, some larger, smaller ones, some deeper and other more superficial, very continuous in parts of the path... and scattered in other parts of the same, even on a stretch of road I cannot see my own footprints... but they are present; and only when you find yourself with a multitude of footprints at the intersection of new paths, you can claim that you took the right path and that the footprints of the trail, although different, are the right ones.

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